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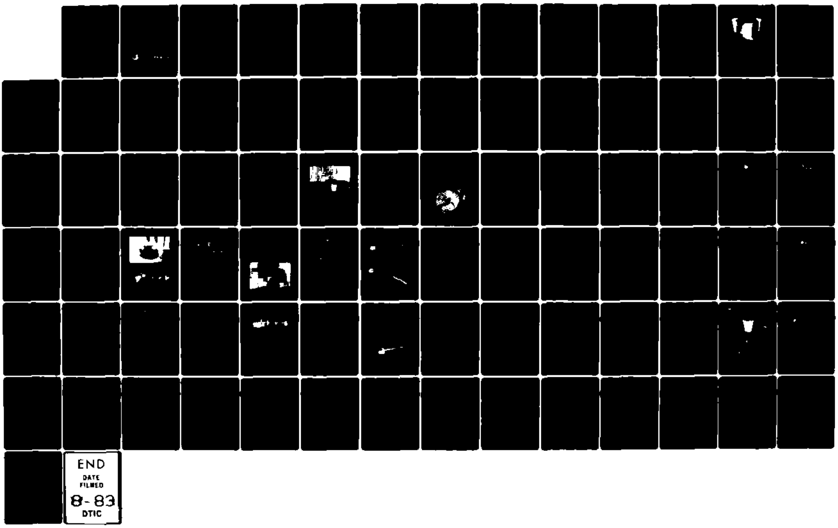

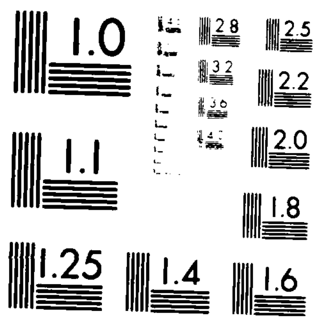

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SELECTIVE AUTOMATIC FIRE EXTINGUISHER FOR CLASS A WITH NOTIFICATION (SAFE CAN). VOLUME I: TECHNICAL REPORT

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Waste Receptacle	Computer Facility	Acoustic Coupling	Automatic
Halon	Local	Receiver	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Currently, fire protection in electronic and computer facilities is provided by full flooding Halon or water sprinkler systems. These systems are expensive and/or damaging to electronic equipment. An original, compact, portable, automatic extinguisher and alarm unit for local extinguishment, such as waste receptacles, is described. An acoustic receiver which detects the alarm and provides fire department notification is also described. Environmental, component, and system testing is discussed and test data presented. This report is divided into two volumes. Volume I consists of the test, and Volume II consists of appendices.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, at the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico, under Contract F29601-81-C-0013, Job Order Number 25051014, for the Engineering and Services Laboratory, Headquarters Air Force Engineering and Services Center (AFESC/RD), Tyndall Air Force Base, Florida.

This report summarizes work done between 7 May 1981 and 31 March 1983. Mr. Joseph L. Walker was the AFESC/RDCS Project Officer.

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This report is published in two volumes. Volume I contains the Technical Report while Volume II contains Appendices A, B, and C.

This report has been reviewed by the Information Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

BACKGROUND

Total flooding Halon and water sprinkler fire suppresion systems are in general use for the protection of buildings and critical electronic equipment. Although these systems provide ample fire protection against total loss and large-scale damage, they are expensive to install and maintain. It is desirable to detect and suppress fires at the incipient stage without the release of a large quantity of expensive or potentially damaging agents and without damage from heat and smoke. For this reason, a small economical extinguisher system that can be easily installed for local detection and fire suppression has a large potential application.

Small fires in administrative disposal receptacles are major causes of fire damage, especially in critical electronic facilities. The need exists for an economical capsulized device which would detect and extinguish fires in their incipient stages. Such a device, coupled with a local alarm and a notification system to the fire department, would provide a versatile and inexpensive fire protection system. The system could provide protection where total flooding systems do not exist and could also be used where local fire suppression would save the unnecessary activation of a total flooding system.

OBJECTIVE

The objective of the effort described herein was to design, construct, test, and evaluate a capsulized device capable of selective, unsupervised extinguishment of Class A combustibles in administrative disposal receptacles in critical electronic facilities and automatic activation of a fire department notification system.

METHOD

The development effort was divided into three phases:

Phase I--

1. Literature and manufacturers search (Appendix A) for existing solutions, partial solutions, and potentially useful components.

2. Generation of a variety of conceptual designs.

3. Evaluation of concepts and components, including limited functionality testing.

4. Recommendation of the most promising concepts.

Phase II--

1. Development of overall test plan.

2. Testing and observations to define environment.

3. Testing and refinement of device components.

4. Refinement of conceptual designs, initial prototype construction, and testing.

5. Recommendation of final designs.

Phase III--

1. Final engineering and construction of prototype systems.

2. Evaluation testing of prototype units, including performance and reliability measurements.

3. Final cost analysis and recommendations.

This plan provides a go/no-go decision point for the continuation of the effort based on the success risk at the end of each phase. The plan also provides for the modification or refinement, based on the research performed, of task definitions for successive phases. For example, the development of an acoustic alarm receiver was added to the effort at the end of Phase II

RECOMMENDED DESIGN

The recommended design consists of a capsulized extinguisher and acoustic alarm mounted on waste receptacles and a remote wall-mounted acoustic receiver connected to the central fire alarm system. A cutaway sketch of the extinguisher/alarm unit is shown in Figure 1. A photograph is provided in Figure 2. The unit consists of a single closed cylinder separated into two compartments by a flexible diaphragm. The lower compartment is connected via a tube to a fusible alloy plug located inside the rim of the waste receptacle. The upper compartment is sealed at the upper end by a valve leading to a vibrating diaphragm air horn. The valve is kept closed by the upward pressure of the extinguishing agent on the diaphragm; the valve is opened by downward movement of the diaphragm when this pressure is released. The upper compartment also contains an optical level indicator. Each compartment is filled

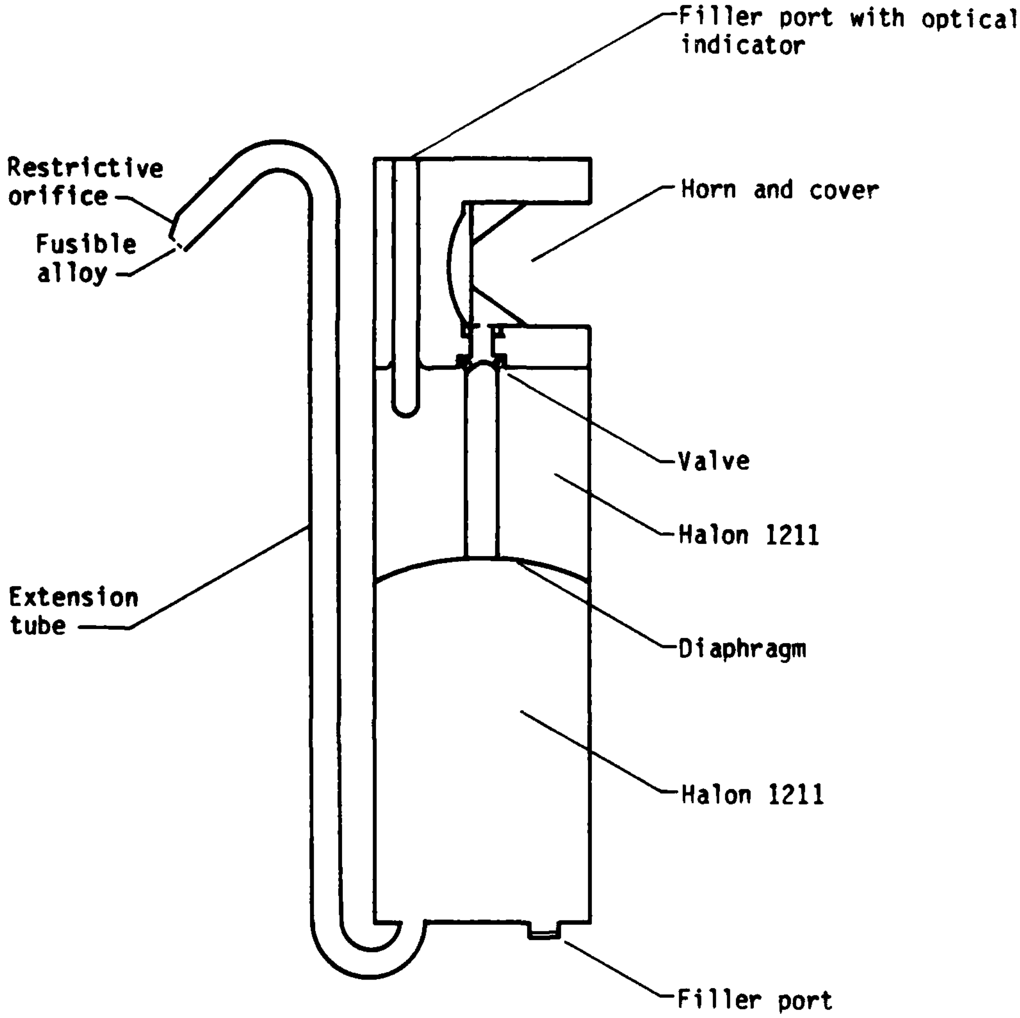


Figure 1. Extinquisher/Alarm Internal Components.

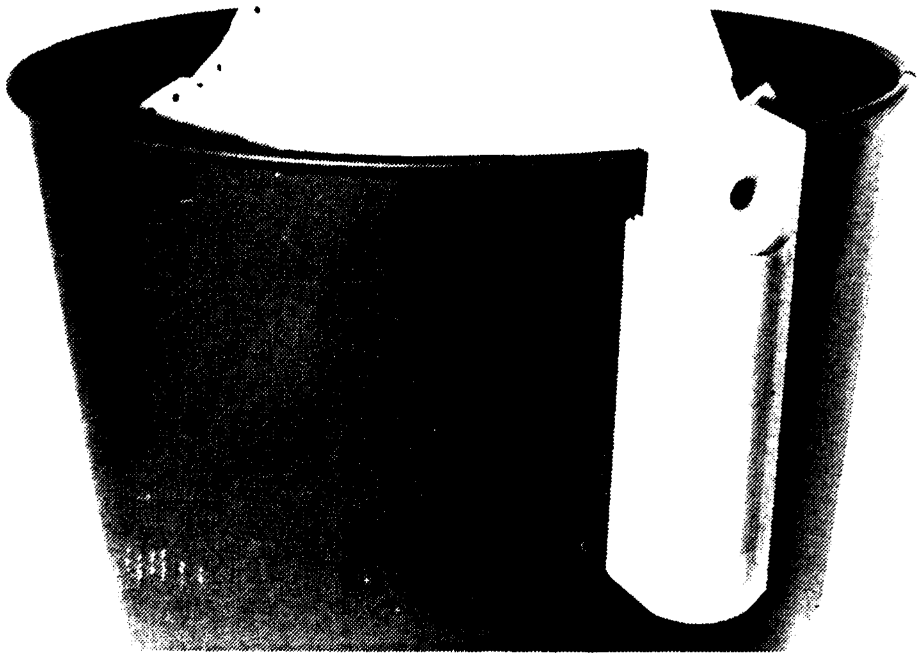


Figure 2. SAFE CAN Extinguisher/Alarm Unit.

with Halon 1211 through a filler port. The unit is protected by a plastic covering which is attached to the waste receptacle by a contact adhesive.

The acoustic receiver is mounted on a wall or ceiling remote from the waste receptacle. The receiver recognizes the alarm signal based on the signal's frequency, intensity, and duration. Once a true alarm signal is determined, the receiver actuates a central alarm signal to the fire department.

Details of the extinguisher/alarm and receiver designs are presented in Section IV and Appendix B. The system developed is called SAFE CAN, derived from the subtask title of Selective Automatic Fire Extinguisher for Class A with Notification.

SECTION II

PROBLEM ANALYSIS

ENVIRONMENT

It is desirable to extinguish a fire in a waste receptacle in the fastest, most reliably efficient, and economic manner. The following general scenario is presented to qualitatively define the thermophysical environment of operation. The results of quantitative environmental measurements are presented in Section III.

The waste receptacles of concern are those found in Air Force computer facilities. These are GSA-supplied metal receptacles painted with enamel, with a round cross section, and nominal 6- and 20-gallon capacities. The fuel loading is primarily computer-related paper and personal items. Likely ignition sources might be smoldering cigarettes, matches, and flammable liquids, especially those that readily vaporize such as computer element cleaners.

A local high heat release zone leading to ignition may begin either near the top or bottom of the waste receptacle. Due to the buoyant rise that transfers heat toward the top of the receptacle and due to the limited supply of oxygen near the bottom of the receptacle, it is expected that the largest flaming combustion (a diffusion flame) will be at the top of the load, regardless of whether smoldering and ignition starts at the top or bottom. To provide for the fastest and surest response of a given sensor, the sensor should therefore be located above the top of the fuel load, which may be any height in the receptacle.

The fuel load may be a stack of computer printouts. Such a ream would present a long-burning fuel load or a long-term smoldering fire of great difficulty to extinguish. Other fuel loads might be crumpled paper, sheet paper, computer cards, and possibly flammable liquids. A great variety of personal item wastes may also be present. For such a varied density and type of fuel load, it is desirable to ensure the most efficient usage of any fire extinguishing agent. Because of the buoyant drafting in a waste receptacle caused by the burning fuel load, it is most beneficial to deliver the effective form of the extinguishing agent at the bottom of the combustion zone. Temperature-time-position profiles were acquired experimentally to accurately design sensor and release positions within the waste receptacle. Additionally, flow patterns were studied to efficiently design for extinguishing agent distribution upon release, especially with the low design-concentration Halons. The anticipated flow pattern within the waste receptacle is shown in Figure 3.

DESIGN OBJECTIVES

Six major design objectives were imposed on the SAFE CAN system from its inception. These objectives helped define and limit the range of potential designs.

The first objective was that the system would be unobtrusive. This required that the extinguisher unit be small. Criteria for smallness were set at a volume less than 3 inches in diameter and 3 inches long, and a weight less than 0.5 pounds. The objective of unobtrusiveness also required that the system not interfere with the use of the waste receptacle. This precluded the use of elements that would block the mouth of the waste receptacle as well as the use of delicate components that could be damaged in the normal filling and emptying of the waste receptacle.

The second objective was that the unit be self-powered. This requirement implied portableness of the extinguisher and allowed application to isolated locations. A third objective was that the unit extinguish Class A, B, and C fires, thereby limiting the potential extinguishing agents. The fourth objective required the device to provide unsupervised extinguishment, implying completely automatic operation. A fifth objective required that the unit remotely activate an alarm to the fire department. This objective implied that the alarm notification system to the fire department be remotely activated by a type of coupling with the extinguisher unit that eliminated wires.

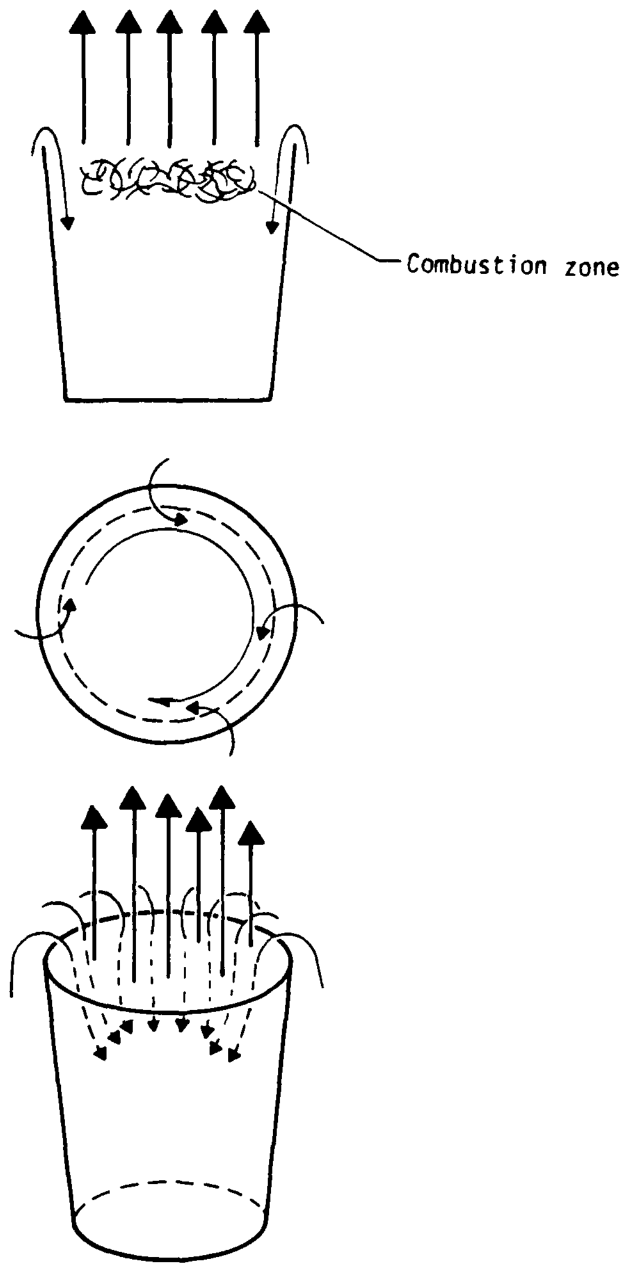


Figure 3. Anticipated Waste Receptacle Fire Circulation Pattern.

The last objective required that the cost of an individual extinguisher/alarm unit not exceed $5 based on a production run of 10,000 units. The ramifications of the $5 limit were the elimination of (1) expensive sensors such as optical, gas analysis, ionization, and thermal analysis; (2) non-integral valves; (3) exotic materials; and (4) complex electronics.

OPTION ANALYSIS

Four fundamental functions that must be performed by any SAFE CAN design were identified. These functions are

1. fire detection (sensor and release mechanisms),
2. fire suppression (agent type),
3. agent storage (container size, material, and mounting), and
4. alarm relay (transmitter, receiver, and extinguisher coupling).

Numerous potential methods of performing each of these functions exist. A literature review of patents and other publications was conducted, and solutions from the fire protection industry were solicited. A bibliography and list of industry contacts is provided in Appendix A. The design objectives, particularly the remote alarm coupling and the cost objectives, severely limited the existing technologies applicable to this effort. Capsulization of the extinguisher and alarm into a reliable and economical package required essentially original work. The options identified during this effort for accomplishing the four functions listed above are presented and are analyzed in the following sections.

Fire Detection and Agent Release

The first event for any fire extinguishing system is for the fire to be detected. The best sensors are those that can detect the fire most rapidly, most reliably, and most economically. The sensor must, of course, be able to generate a signal of sufficient magnitude to release the extinguishing agent. The general categories of detectors are as follows:

- Heat detectors
  - Thermocouples, thin films, and so on
  - Bimetallic or metallic
  - Electrical conductivity
  - Fusible alloy
  - Liquid or gas expansion
  - Rate-of-rise via pneumatic or thermoelectric effect
- Smoke detectors
  - Ionization type
  - Photoelectric type
- Flame detectors
  - Infrared
  - Ultraviolet

None of the above detectors can be said to be always the fastest detector. For instance, a smoldering fire will yield smoke before a large emission of radiation so that a smoke detector may be the fastest; in contrast, a highly flammable liquid would almost immediately yield a large quantity of radiation that is rapidly detected by a flame detector. A heat detector may not respond as quickly as a smoke detector to a smoldering fire or as quickly as a flame detector to a liquid fire, but it could provide moderately fast response to both types of fires as the heat of the fires approaches dangerous levels.

The selection of a fire detector depends on (1) the space to be covered, (2) the types of fires anticipated, (3) the response required, (4) the detector's reliability, (5) its durability, and (6) cost. By definition in this effort, the space to be covered is small and semiconfined, i.e., the inside of a waste receptacle. The types of fires anticipated range from smoldering long-burning fires to flaming liquids. It is anticipated that the most common fire will be flaming paper products. The detector response required is fast. Originally it was desired to detect the fire within 5 seconds of ignition. This proved to be unrealistic, and a design goal of 30 seconds was established. The fire must be detected reliably for an anticipated unit life of 5 years. The detector must be able to withstand the shock and impact of the waste receptacle being emptied and dropped and discarded objects entering and leaving the receptacle. The cost of the detector and the balance of the extinguisher/alarm unit should not exceed $5.

The economic consideration essentially eliminates the use of smoke or flame detectors because these units, including power supply and signal generators, cost more than is allowed for the entire extinguisher/alarm unit. These detectors are best suited for large-area protection coupled with a full flood system. Of the heat detectors listed, only fusible alloys and liquid or gas expansion were considered viable for the SAFE CAN application. All of the electrical sensors--thermocouples, thin films, and electrical conductivity or resistance--require a power source, i.e., battery and conditioning/logic circuitry, which leads to maintenance and excessive cost. These types of sensors would continually draw power from the battery, making reliability over the expected life of the unit questionable. The bimetallic and metallic sensors provide little driving force for mechanically activating the SAFE CAN unit and are either slow in responding or very delicate. The rate-of-rise sensors are more sophisticated, i.e., more costly, versions of the other types of sensors and must generally be coupled with a limiting temperature sensor for reliability. These sensors would only be considered if the other sensors proved inadequate.

Three types of fusible alloy heat detectors were identified, including a fusible alloy link as part of an electrical circuit, a fusible alloy link mechanically restraining a spring-actuated valve, and a fusible alloy plug sealing a pressurized container. Of these the electrical fusible link was considered inappropriate for the same reasons as the other electrical detectors. Both the mechanical spring restraint and fusible alloy plug were considered viable heat detectors for this application. In both cases there must be a trade-off between response and durability. The fusible plug was considered especially desirable because of its extreme simplicity and low cost. The plug becomes its own valve mechanism, eliminating moving parts and material compatibility problems.

The liquid or gas expansion heat detectors were considered the only viable alternatives to the fusible alloy detectors for this application. The detector would be self-powered, i.e., the heat input from the fire could produce sufficient force and displacement to operate a release valve. The mechanism would be inexpensive, similar to the mechanical fusible alloy detector. However, these sensors would suffer from slow response if the actuating force and displacement required were very large.

Fire Suppression

The general categories of extinguishing agents from which to select are

- water
- CO_2 and inert gases
- foams
- dry chemicals
- Halons
- others

Water, CO_2, inert gases, and foams are inappropriate because of the quantities involved. Dry chemicals are more appropriate for liquid-fueled and directly accessible fires. Other agents are not desirable because of cost, availability, and/or lack of performance data. Halons are most appropriate because of the small quantities required and their ability to find their way through a semiblocked entry, such as the tortuous pathways in a waste receptacle. The boiling points at 1 atmosphere pressure of Halons 1301, 1211, and 2402 are -72°F, 26°F, and 117°F respectively. The vapor pressures are inversely proportional to the boiling points as shown in Figure 4 (Reference 1).

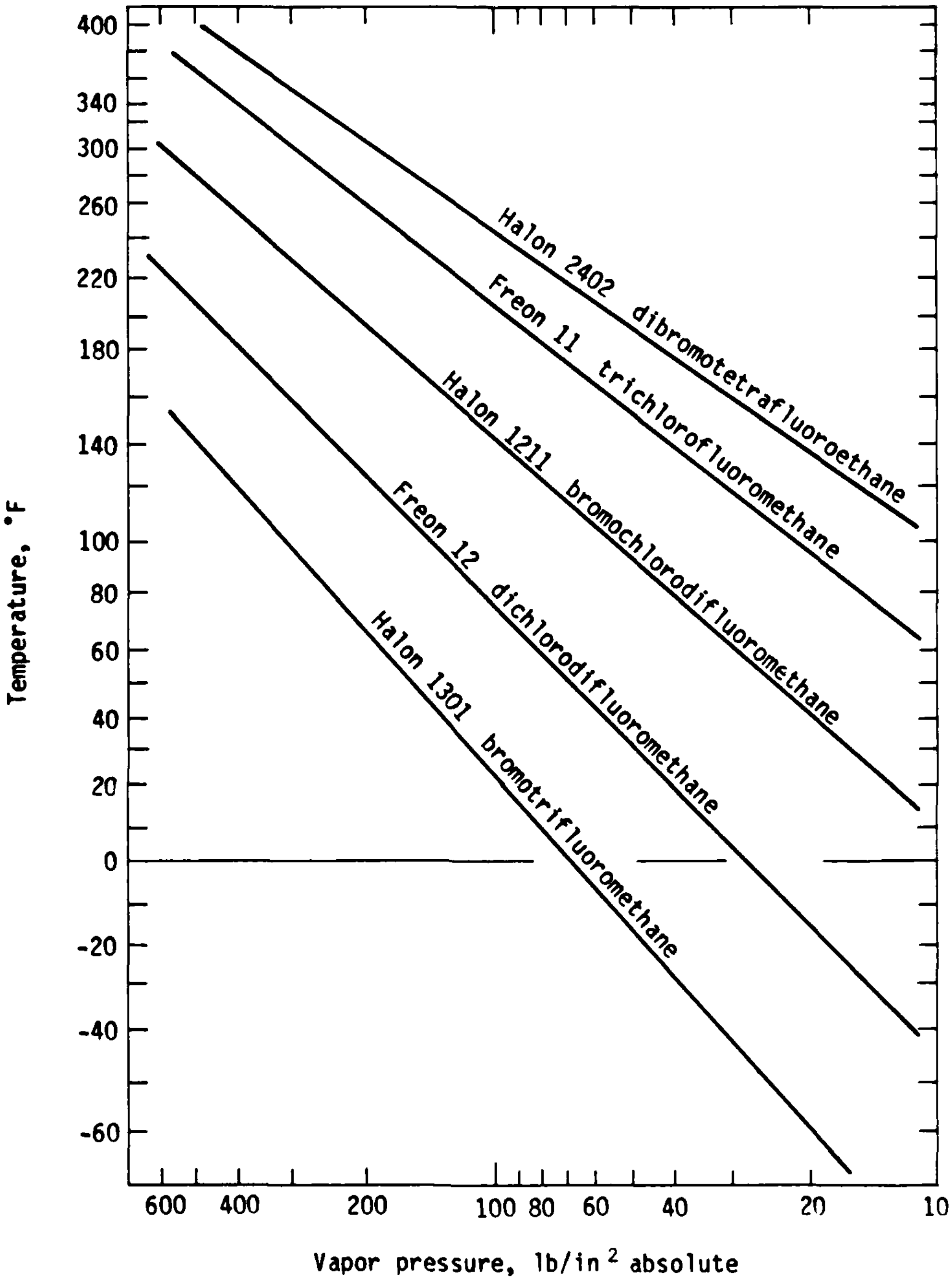


Figure 4. Vapor Pressure of Halons and Freons versus Temperature (Reference 1).

At normal room temperatures Halons 1301 and 1211 would provide sufficient pressure to propel the extinguishing agent onto the fire. Halon 2402, and Halon 1211 at temperatures below approximately 35°F, would require an additional driving force such as pressurized N_2 or possibly a mixture of Halon 1301 or Freon 12 with the other Halons. Heat from the fire could also drive the extinguisher; however, it is desirable to extinguish the fire before a significant amount of heat is produced. Although sufficient driving pressure to rapidly expel the extinguishing agent and rapidly generate high Halon concentration is desired, too high a pressure and delivery rate may blow burning material from the waste receptacle, causing multiplication of ignition sources--a very undesirable event.

Because the Halons must be in a gaseous state to intercede in the combustion process and because the combustion tends to buoyantly carry gases from the waste receptacle, the delivery of the Halon agent may be critical. Halon 1301 would be delivered most effectively at the bottom of the waste receptacle. or at least forcibly directed toward the bottom of the receptacle. From there the Halon gas would rise through the fuel load and be drawn through the fire by the bouyant draft. If Halon 1301 were delivered too high above the fire it could be carried off by the draft from the fire without reaching the combustion zone and extinguishing the fire. Halon 2402 would have to be directed at the combustion area. If Halon 2402 were not exposed to the heat of the fire, it would remain a liquid and pool at the bottom of the waste receptacle until the temperature there increased sufficiently to rapidly vaporize the agent. This may not happen until the fire burns to the bottom of the receptacle (see temperature data in Appendix C). Halon 1211 appears to offer a desirable combination of liquid and vapor states when discharged under pressure from an extinguisher. Typically, Halon 1211 from a pressurized container will be 70 percent liquid/30 percent vapor when it leaves the discharge nozzle. The gaseous Halon delivered at the rim of the waste receptacle may be drawn into the fire or carried off. The liquid agent will descend into the receptacle as it vaporizes, delivering gaseous Halon to many levels in the fuel load. Unlike Halon 2402, Halon 1211 would not require heat from the fire to cause vaporization. Although Halon 1211 is the least efficient of the three Halons (Reference 1, Figure 2) in terms of concentrations required to extinguish a laboratory diffusion flame, it was considered the most promising agent for this application due to the pressure and vaporization properties just discussed. Combinations of the different Halons were also considered as potentially desirable extinguishing agents.

Agent Storage

The size of the extinguishing agent container is primarily determined by the amount of agent needed to suppress a fire and the structural requirement for strength and durability. As an example, consider the volume requirements for Halon 1211, the most likely agent, as stated in the NFPA Standard 12B (Reference 2), a nonconservative requirement for the application at hand. The nominal quantity of Halon 1211 is 5 percent for many liquid fuels and flaming solids. This concentration may be required for a period of time. The small office waste receptacle supplied by GSA is 6.0 gallons (0.802 cubic feet or 1368.0 cubic inches). From Table 2-5.2 in Reference 2 the Halon 1211 weight requirement per cubic foot of hazard volume (pounds per cubic foot) is 0.0234 at 70°F and lower at higher temperatures. Therefore

$$\frac{\text{W--lb agent}}{\text{V--ft}^3\text{ protected volume}} = 0.0234$$

so, W = 0.0234 (0.802) = 0.01877 pounds of Halon 1211 required. The liquid density of the Halon is 1830 kg/m^3 at 20°C (1.82 g/l = 114.4 lb/ft^3). To contain the 0.01877 pounds of Halon, the volume required is (1 ft^3/114.4 lb) x 0.01877 lb x (1728 in^3/ 1 ft^3) = 0.283 in^3. This requires a cylinder of 0.5 inches in diameter by 1.44 inches in length. However, a concentration of 10 percent may be required so that 0.038 pounds of Halon in a 0.566-in^3 cylindrical container of 0.5-inch diameter by 2.876-inch length would be required. Additionally, a 10-percent concentration may be required for some period of time, say 10 minutes in a smoldering fire, whereby buoyancy and drafting would cause dilution of the initial agent release. If the total can volume of agent was totally replaced every 10 seconds, then to keep a 10-percent concentration for 10 minutes would require 2.3 pounds of Halon in a cylinder 3.0 inches in diameter by 4.87 inches in length. (Halon 1211 costs about $2.04/lb GSA.) Thus, the extinguishment of a smoldering combustion may not be assured if other design objectives are to be met. In a SAFE CAN this may be acceptable since notification of an incident will be provided locally and to the fire department.

To provide an initial concentration of 25 percent, which would rapidly extinguish most fires, the required extinguisher volume and size would be 1.417 cubic inches and 1.5 inches in diameter by 0.802 inches in length for a 6.0-gallon waste receptacle and 4.723 cubic inches and 1.5 inches in diameter by 2.673 inches in length for a 20-gallon waste receptacle. Rapid fire suppression would reduce the drafting effect and provide a safety factor of 2.5 if half of the agent is buoyantly carried off.

There are two economic choices for the outer container which would be used to hold the extinguishing agent. These two choices are metal or plastic. The final choice will depend on cost, durability, long-term integrity with some agents, and design applicability. Considering Halon as the agent, the usual container is anodized aluminum. No actual data were found on the application of plastics with Halon--although projections based on accelerated simulation tests indicate that Halons are compatible with some plastics. It is thought that engineering plastics could reliably contain the Halons but the costs may be more than for aluminum. Complexity of the extinguisher design may also dictate a multiplicity of materials to reliably meet the economic objective.

When a Halon is heated it will generate a pressure (its vapor pressure) due to the conversion from liquid to vapor. If Halon 1211 is heated to 150°F, the vapor pressure is approximately 125 lb/in^2 absolute. Therefore, the container must withstand a significant pressure. For other agents the container may be pressurized with a gas such as nitrogen. The round walls of a cylinder provide maximum strength for a given thickness of material (spherical being of impractical cost). Cylindrical shapes also provide for economic manufacturing as compared to rectangular cross sections.

Alarm Relay

Although the SAFE CAN must automatically detect and extinguish waste receptacle fires, it must also perform another and possibly more important sequence of functions, that is, detection, local alarm, and alarm telemetering. These functions are important for two reasons. First, they alert personnel in the vicinity to the possibility of imminent danger. Second, they offer redundant extinguishment options (i.e., fire department or local personnel action) should the SAFE CAN fail to completely extinguish a smoldering fire. To accomplish these objectives the alarm must be reliable, economical, and compatible with the rest of the SAFE CAN unit. The previously stated design objectives apply to the alarm as well as the extinguisher functions. Alarm telemetry considerations in this effort ended at the interface to a standard central alarm system assumed to exist wherever notification to the fire department is desired.

Development of an alarm system completely independent of the extinguisher system was considered but was discarded for two reasons. First, the duplication of the fire detection mechanism would add cost to the SAFE CAN unit. Second, if the extinguisher were activated first, the fire could be extinguished without notifying the fire department that a fire had occurred. Or the fire could be suppressed but not extinguished, thereby allowing the fire to rebuild before activating the alarm and possibly presenting a greater hazard,as no suppression capability would remain. Based on this assessment, it was decided that the alarm must be activated by the same fire detection mechanism as the extinguisher.

Three types of alarm transmission mechanisms were considered. These included hard-wired electrical, RF transmission, and sonic transmission. Each could be activated by a switch or valve coupled to the fusible alloy or the liquid or gas expansion heat detectors. The hard-wired electrical system would consist of a switch, activated by the heat detector, connected to a current monitor through cord extensions and special wall receptacles. A change in the switch position would be detected by the circuit current monitor, and a signal to the central alarm system would be transmitted. A special mechanism would be required to allow the waste receptacle to be disconnected from the wall socket during waste collection. The system would not require a power source on the waste receptacle. The hard-wired electrical system would be extremely inexpensive once installed, but it was eliminated because it would limit the location of waste receptacles, interfere with normal waste receptacle servicing, and would be susceptible to human error, rendering the system inoperative.

The RF system could be virtually self-contained on the waste receptacle. A switch coupled to an extinguisher detector would activate a simple RF transmitter which would send a signal to a wall-mounted receiver. The receiver would monitor any number of transmitters within the transmission range. Upon detection of a signal the receiver would activate local and central alarm systems. Advantages of this system include complete waste can mobility, reliable signal detection, easy functional testing, large area coverage, small and durable packaging, and quick and simple installation. Disadvantages include the need for adequate electrical batteries, necessitating frequent periodic checks and battery replacement and high initial parts and battery replacement costs. Because of the high costs involved, this approach was not actively pursued.

Two sonic alarm transmission mechanisms were considered. One utilized an electric buzzer to transmit an acoustical signal which could be detected by a wall-mounted receiver. The sequence of events would be essentially the same as the RF alarm except that coupling would be acoustic rather than electromagnetic. This electrical sonic alarm was not considered feasible for the same reasons as the RF alarm.

The second type of sonic alarm considered involved a whistle or horn which could be driven by the extinguishing agent, a separate vaporizing liquid such as Freon 12, or a compressed gas. The sonic alarm would be activated by a valve coupled to the extinguisher heat detector, and the acoustic signal would be detected by a wall-mounted acoustic receiver. The transmitter unit would be completely self-contained, providing the desired waste receptacle mobility. Hardware costs would be very low. Depending on the amount of driving fluid required, the package could be small. No electrical power supply would be required. The main concern with this sonic alarm was the discrimination of the alarm signal from background noise. Several solutions or discriminating characteristics were considered, including signal frequency or frequency combinations, signal intensity, and signal duration or pattern. Because of its simplicity, low initial and maintenance cost, and extinguisher compatibility, this alarm transmission approach was considered most applicable to the SAFE CAN concept. The most promising sonic transmitter was a vibrating diaphragm horn similar to those used at sporting events and for personal defense. Initial investigation indicated the signal could be discriminated based on frequency, intensity, and duration.

INITIAL CONCEPTS

Based on the design objectives and problem analysis presented in the preceding sections, the following component options were selected for further investigation and development.

Detection:

1. Fusible alloy (plug type)
2. Liquid or gas expansion

Extinguishing agent:

1. Halon 1211
2. Halon 2402

Container material:

1. Aluminum
2. Plastics

Alarm:

1. Vapor-driven horn
2. Electric buzzer

The first option listed under each component type was considered as the primary candidate. Three conceptual designs were developed, based on the coupling of the extinguisher and alarm. The three designs attempt to utilize all of the possible components in groups that provide the most effective system operation.

The first concept is shown in Figure 5. The Halon extinguishing agent is used to extinguish the fire and drive the alarm. The requirement of driving the alarm limits the Halon choice to Halon 1211 because of the driving pressure requirements of the alarm. A check valve in the Halon compartment is maintained closed by a pressurized gas such as nitrogen. When the fusible alloy plug melts, the pressurized gas is released. The vapor pressure of the Halon opens the check valve, exposing ports for both the extinguishing agent and the air horn alarm. The ratio of agent delivered to the fire and to the alarm is controlled by sizing of these ports.

Figure 6 shows the second conceptual design. In this design separate compartments contain the Halon extinguishing agent and a vaporizing liquid, such as Freon 12, to drive the air horn alarm. A vaporizing liquid such as Halon 2402 or Freon 11 is contained in a compartment exposed to the heat of the fire, forming a vaporizing liquid sensor (VLS). As the vapor pressure of the liquid increases and vapor is given off, deformable diaphragms open valves in both compartments, discharging the extinguishing agent to the fire and vapor to the alarm.

The third concept, shown in Figure 7, utilizes a fusible alloy plug detector and an electric buzzer alarm. The vapor pressure of the Halon extinguishing agent, acting on a diaphragm, maintains an electrical switch in the open position. When the fusible alloy plug releases the exinguishing agent, a spring closes the electrical switch, activating the electrical alarm buzzer.

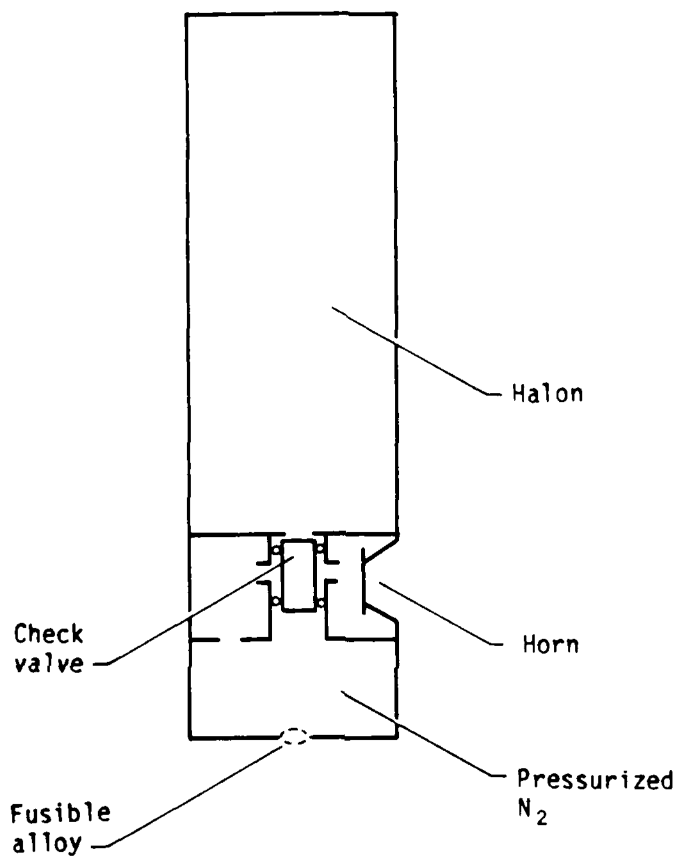


Figure 5. SAFE CAN Concept 1.

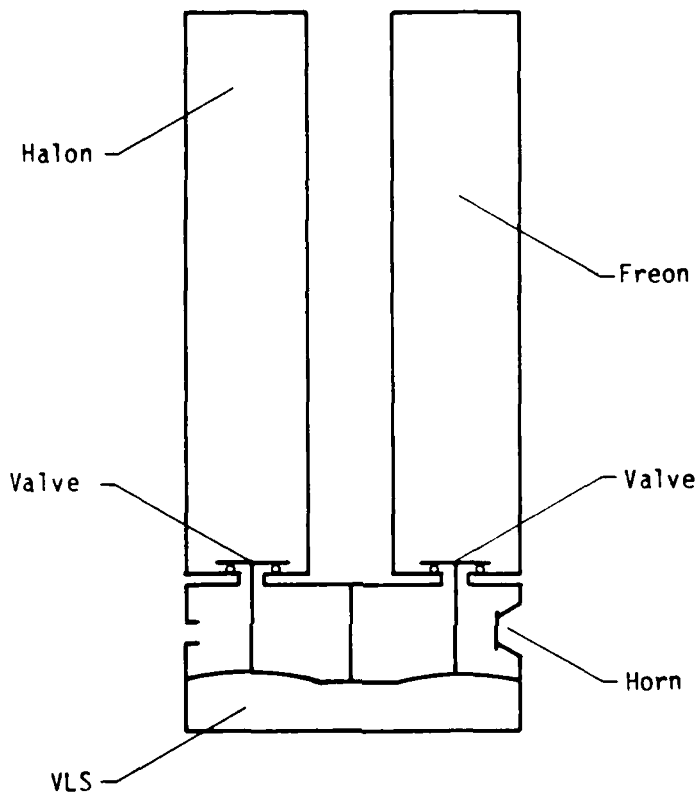


Figure 6. SAFE CAN Concept 2.

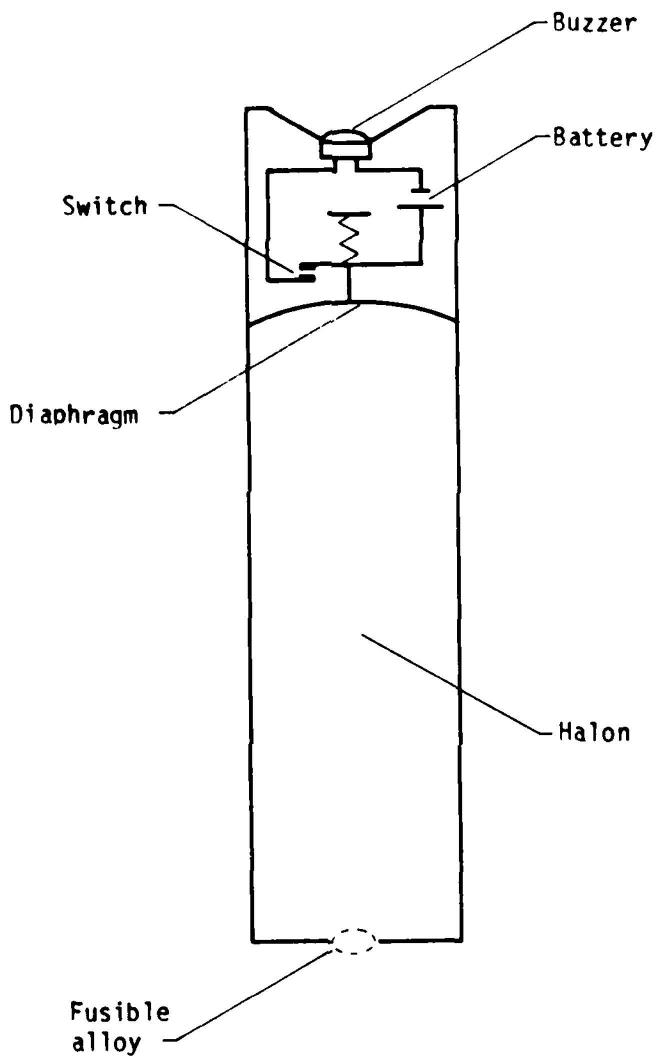


Figure 7. SAFE CAN Concept 3.

SECTION III

TEST PROGRAM

OVERVIEW TEST PLAN

The SAFE CAN development and evaluation testing was separated into four categories as shown in Table 1. The Exploratory/Environmental Tests (Category I) were used to quickly verify concepts, uncover unforeseen effects, and quantitatively define the environment in which the SAFE CAN must operate. Component Testing (Category II) allowed quantitative comparison of the performance of SAFE CAN component and design options. During Initial System Testing (Category III) complete systems and subsystems were tested and refined. Extensive System Evaluation Testing (Category IV) was conducted to demonstrate the reliability, durability, and performance of the final SAFE CAN design. Table 1 also lists the tests that were conducted within each category.

TABLE 1. TEST PLAN STRUCTURE

CATEGORY I: Exploratory/Environmental Tests

1. Temperature versus Time
2. Environmental Noise
3. Exploratory Design Tests

CATEGORY II: Component Tests

4. Fusible Alloy
5. Vaporizing Liquid Sensor
6. Acoustic Coupling
7. Agent Discharge

CATEGORY III: Initial System Testing

8. Extinguisher/Alarm Subsystem
9. Total System

CATEGORY IV: System Evaluation Tests

10. Primary System
11. Toxicity

Although the tests were conducted somewhat sequentially, proceeding from Category I to Category IV, there was a large degree of overlap between the various categories. Testing of the most promising concepts received the highest priority. Environmental data were collected throughout the test program. All testing was conducted at the Civil Engineering Research Facility (CERF) operated by the New Mexico Engineering Research Institute (NMERI). Equipment used during the test program included a Sony HVC 2200 color video camera and SL 2000 video recorder, a multichannel Acurex Autodata Ten/5 calculating data logger with type K thermocouple sensors, Mine Safety Appliance (MSA) Samplair pump and detector tubes, a Tektronix WP 1221 signal processing system, an Ampex PR 2200 tape recorder, a Bruel and Kijaen (B&K) type 2203 precision sound level meter with 1613 octane filter set, and miscellaneous laboratory equipment.

TEST DESCRIPTIONS AND RESULTS SUMMARIES

This section describes in detail the tests listed in Table 1. Reasons for conducting the tests, the method of accomplishing the tests, and conclusions indicated by test results are presented. Complete test data are provided in Appendix C.

Category I: Exploratory/Environmental-- Temperature Versus Time

The purpose of these tests was to determine temperature ranges, distributions, and time histories for waste receptacle fires. This information was used to establish response criteria, safety criteria, and sensor location for SAFE CAN.

Temperature readings were recorded at short intervals from six locations (Figure 8) in the waste receptacles using the automatic data logger. Four thermocouple arrangements, shown in Figure 9, were used to determine temperature distribution. Arrangement 1 was used in initial tests to monitor radial and vertical temperature distribution. Arrangement 2 was used to measure radial asymmetry. Arrangement 3 was used to measure temperatures above the rim of the waste receptacle. Arrangement 4 was used during system tests.

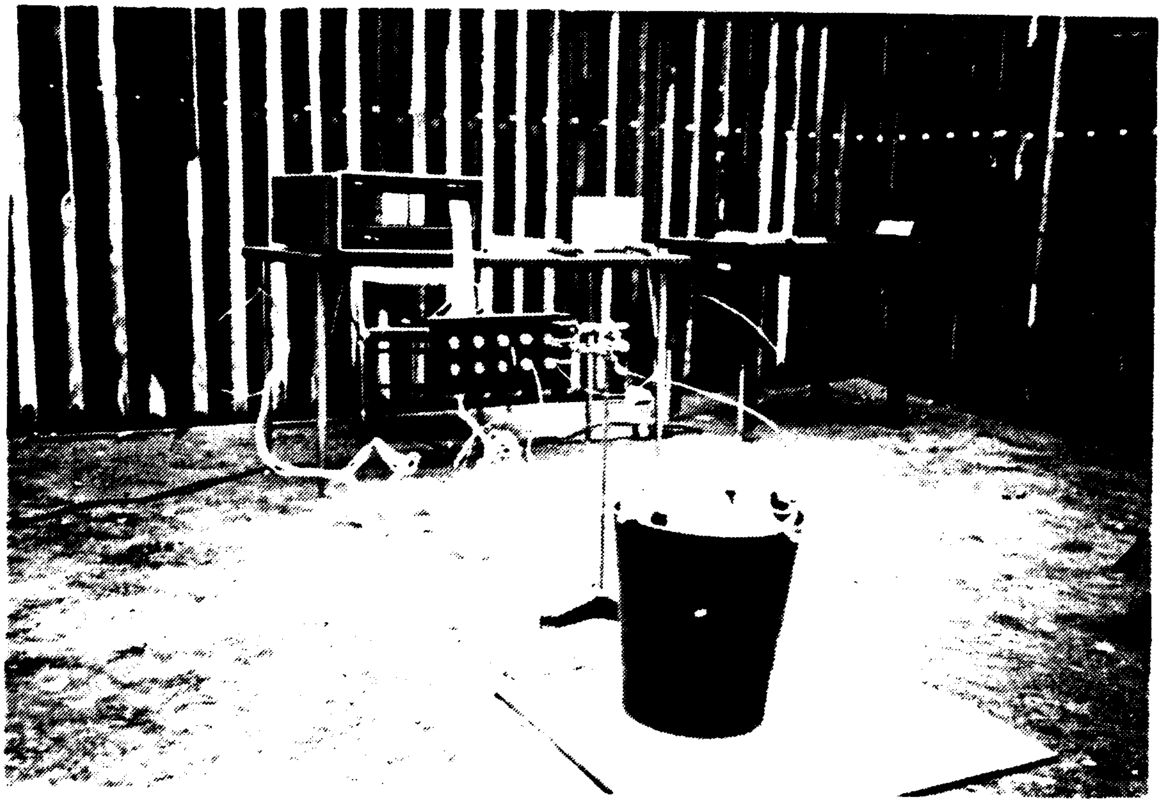


Figure 8. Fire Temperature Measurement Apparatus.

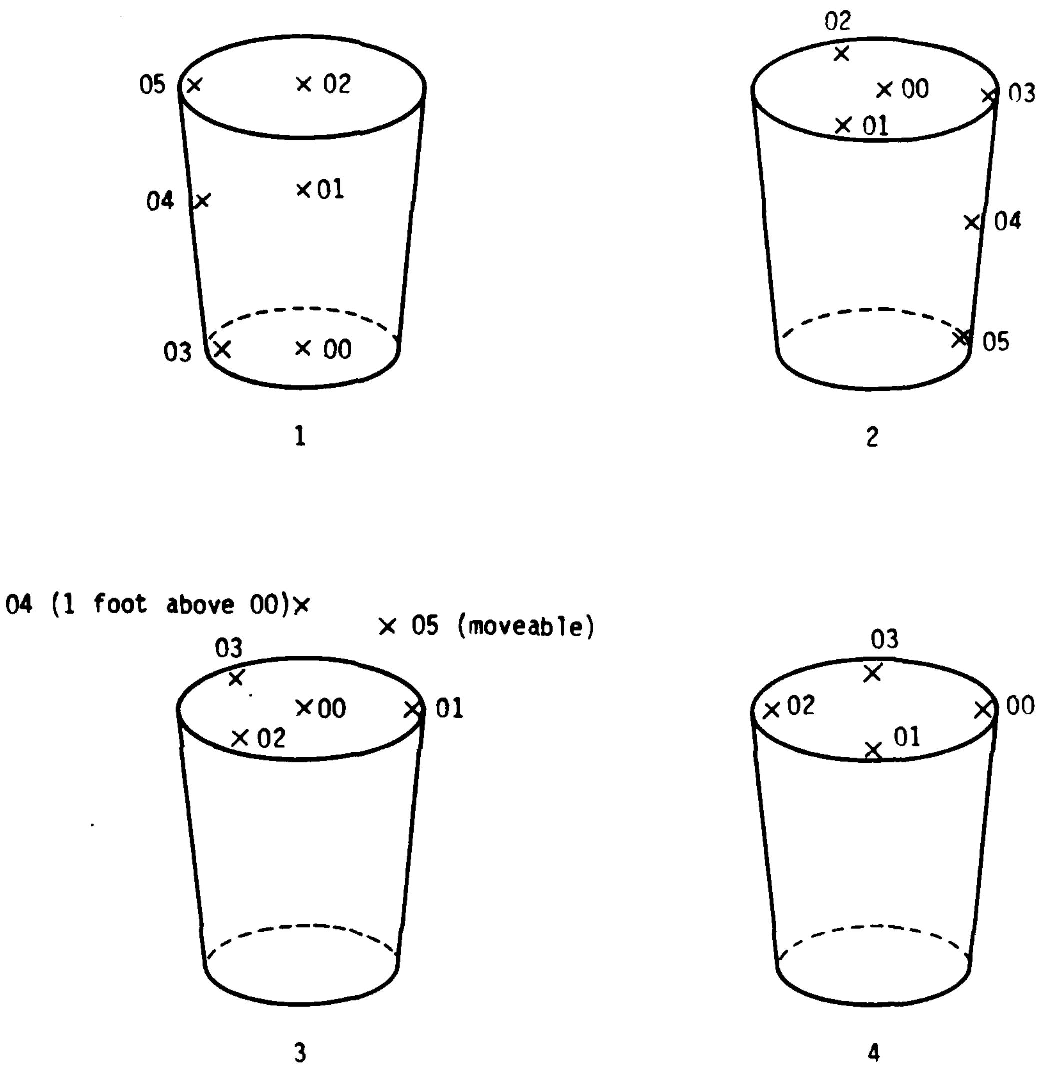


Figure 9. Thermocouple Arrangements.

Fires in both the small and large waste receptacles were monitored. Light (<1/2), medium (1/2 - 3/4), and full (>3/4) fuel loads were tested. Fuels included crumpled paper, ream paper, and cloth. Thirty waste receptacle fire tests were made. Figure 10 shows a temperature test in progress. Temperatures were also monitored during Category III and IV tests.

Figure 11 shows a temperature versus time plot for a paper fire in a small waste receptacle. The fuel load consisted of 12 sheets of crumpled computer paper filling the waste receptacle approximately three-fourths full. The fire was lit at the top center of the fuel load. Thermocouple sensor arrangement 2 was used. Time zero on the plot was the first reading where a temperature greater than ambient was recorded, approximately 5 seconds after ignition.

Figure 11 illustrates many of the characteristics found to be typical of waste receptacle fires. Peak temperatures range between 900°F and 1600°F. Peak temperatures are localized and of short duration. Once burning is

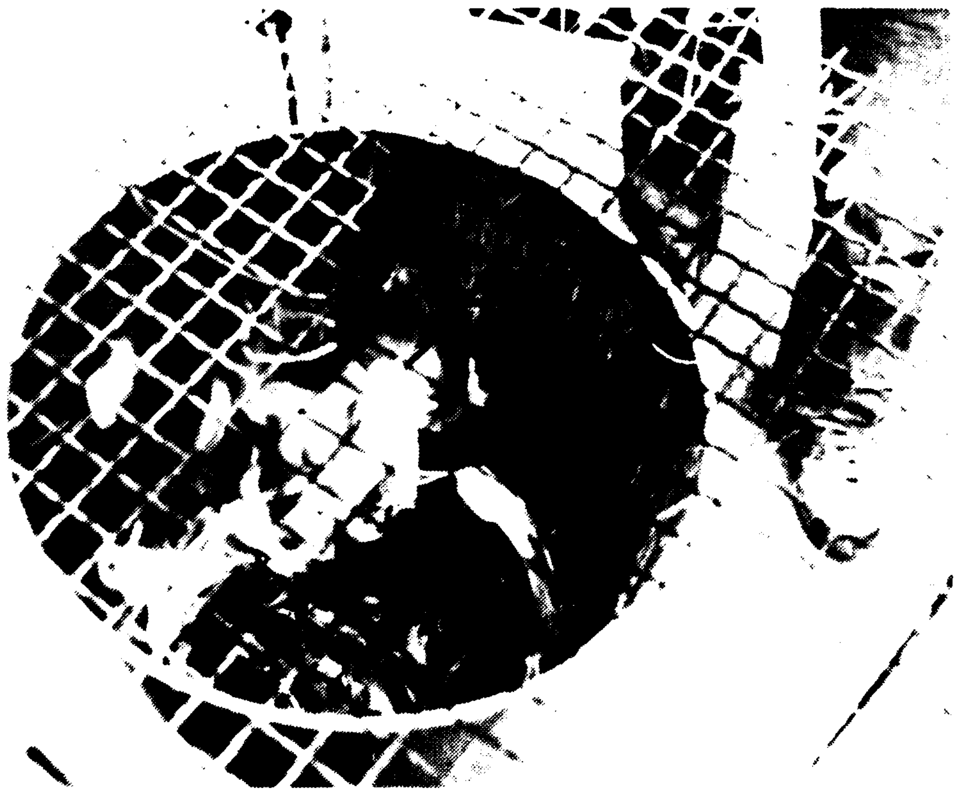


Figure 10. Fire Temperature Test.

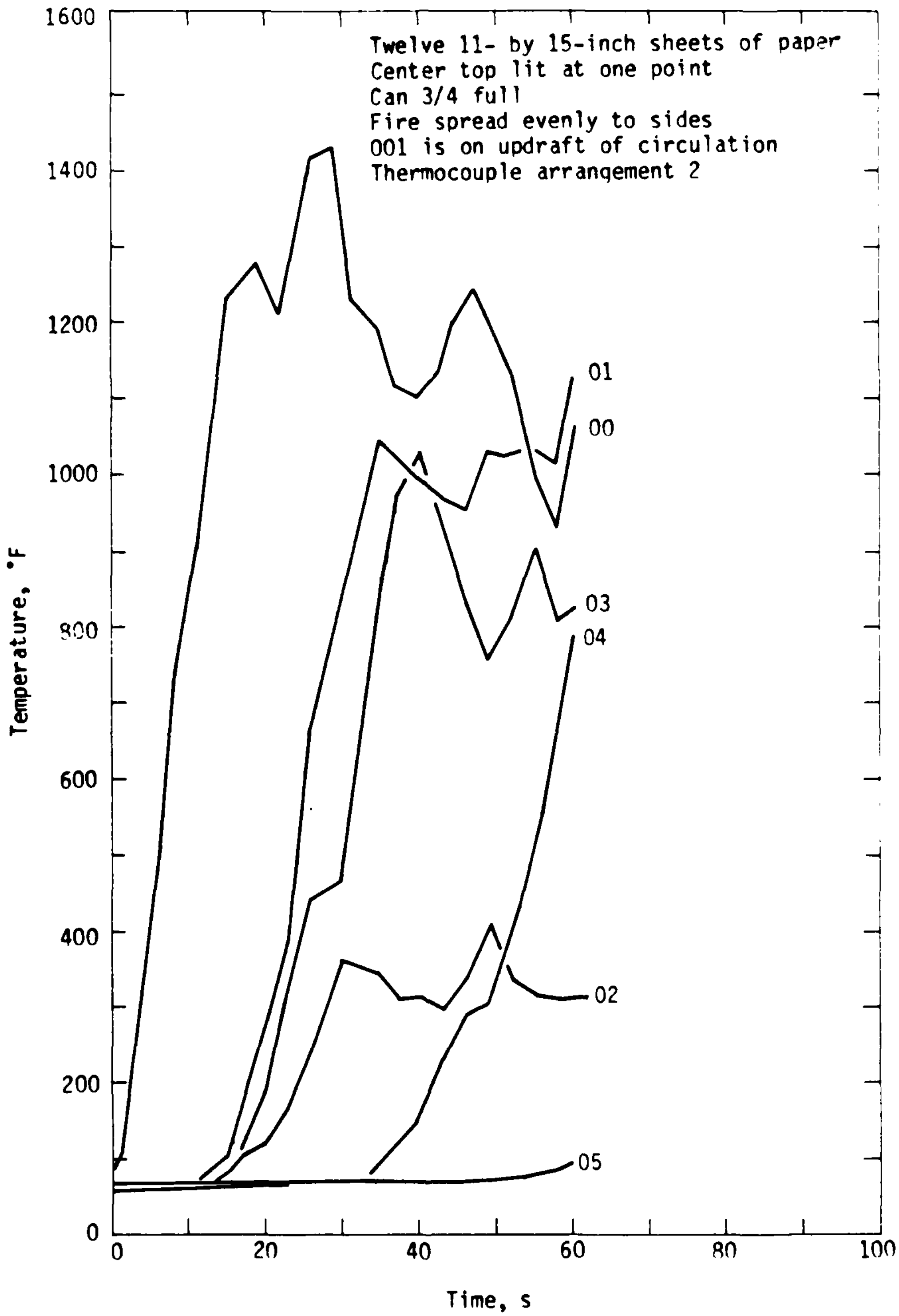


Figure 11. Temperature versus Time for a Waste Receptacle Fire.

well established, maximum temperatures at the rim stabilize between 800°F and 1200°F. Temperatures below the top of the fuel load lag behind those above the fuel load except where ignition occurs immediately adjacent to or below the point in question. The temperature distribution at the rim of the receptacle varies significantly. This appears to be caused by an asymmetric circulation pattern as shown in Figure 12. The down draft portion of the circulation covers approximately one-fourth to one-third of the circumference of the rim of the receptacle and does not extend inward to the center of the receptacle. When no draft is present, this circulation pattern is unstable and tends to wander about the rim of the receptacle, appearing and disappearing at a thermocouple for short periods of time. In tne presence of even a slight draft, the pattern appears to stabilize and can maintain one sector of the rim at a much lower temperature than the rest. The lowest rim temperatures measured during these tests always exceeded 200°F. The circulation pattern appeared to be independent of ignition location. The lower the top of the fuel load in the receptacle, the more uniform the rim temperatures became. The time between the first and last sensors in which temperatures exceeded 200°F was as much as 32 seconds. In several cases a single thermocouple sensor recorded temperatures in excess of 1000°F, in a localized flame, 5 to 10 seconds before any of the other sensors reached 100°F.

The temperature-versus-time tests indicated that the best location for a single-point heat detector would be in the center of the waste receptacle at rim level. This location is impractical because it would interfere with normal use of the receptacle. The next best location is just inside the rim of the receptacle. A continuous loop around the rim or a partial loop covering more than one-third of the circumference, or even two point sensors on opposite sides of the can, would provide a higher probability of sensing a high-temperature zone than would a single point sensor.

Fire ignition does not appear to be a useful benchmark for measuring response time. Detectable changes in temperature outside the waste receptacle which could cause the fire to spread require anywhere from seconds to minutes to develop after ignition, depending on fuel type, load, distribution, and ignition location. A more useful response criterion would be the time between the temperature at the rim of the can exceeding a threshold value, say 200°F,

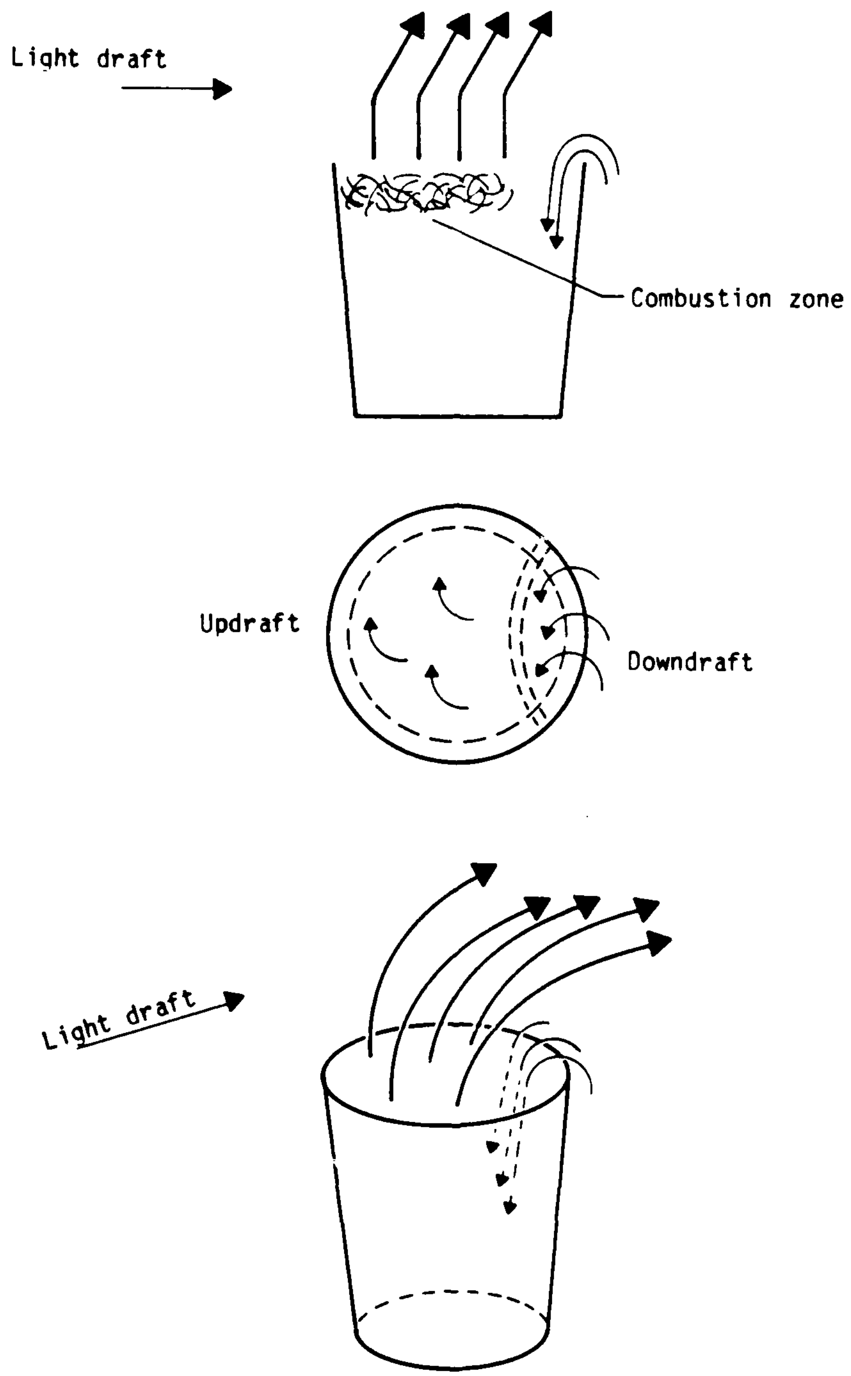


Figure 12. Observed Waste Receptacle Fire Circulation Pattern.

and detection of the fire by the SAFE CAN. For comparison purposes, the response of the heat detector exposed to a constant temperature was used.

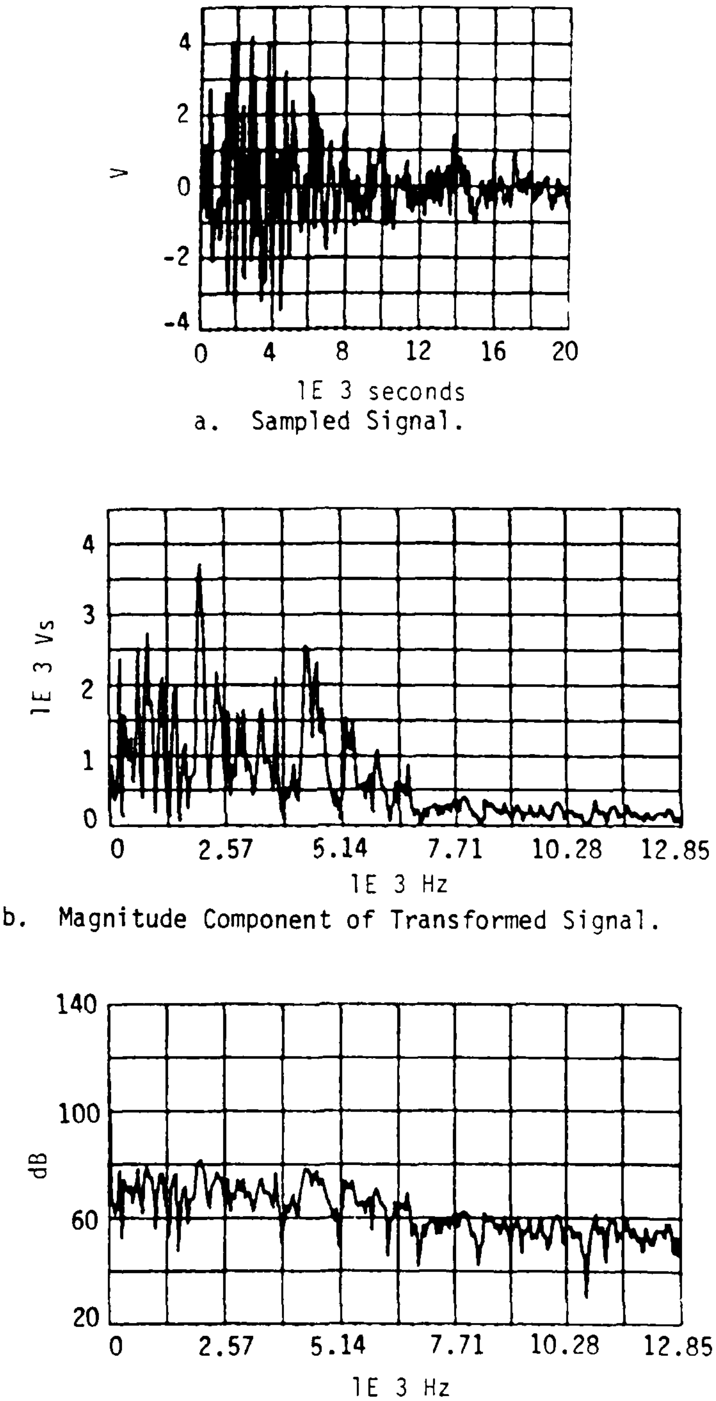
In view of the high temperatures produced in these fires, it would be desirable to mount the SAFE CAN outside the waste receptacle where the contained Halons would not be directly exposed to these temperatures. If the SAFE CAN were mounted inside the waste receptacle and a release valve malfunctioned, the vapor pressure produced by the Halon could quickly exceed 600 lb/in^2. The container would either have to be designed to withstand these high pressures or have a pressure release mechanism, both options being expensive. Another possibility would be the use of a plastic container. Exposed to high temperatures the plastic would melt, releasing the Halon and acting as its own pressure release mechanism.

Category I: Exploratory/Environmental -- Environmental Noise

The purpose of this test was to determine the acoustic environment in which a sonic alarm would have to operate. The acoustic signal produced by SAFE CAN must be distinguishable from the background noise present in computer facilities.

Noise recordings were taken at 17 locations in three computer facilities: the University of New Mexico (UNM) computing center, the Air Force Weapons Laboratory (AFWL) computer center, and the AFWL Data Conversion Branch (ADDE) computer room. The B & K noise meter was used as microphone and amplifier. The recordings were made on an Ampex RP 2200 instrumentation recorder. A Fourier spectrum analysis was later performed on 10-millisecond and 20-millisecond samples of these recordings. The Tektronix signal processing system was used to perform the analysis. Acoustic receivers tuned to the selected alarm frequency and set for various sound level thresholds were later placed in the UNM computer facility to monitor false alarms of an acoustic receiver over longer time intervals.

Figures 13 and 14 are samples of the noise recorded at t. locations in the ADDE computer room. Plot a in each figure is the original sampled signal. Plot b shows signal voltage versus frequency, while plot c shows calculated decibel level versus frequency. The decibel level was calculated using the formula : $dB = 20\ [\log(\text{voltage}) + K]$

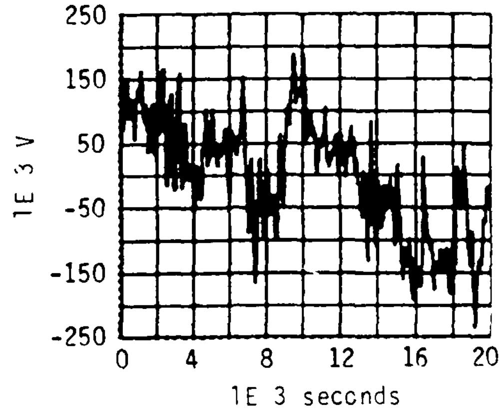


a. Sampled Signal.

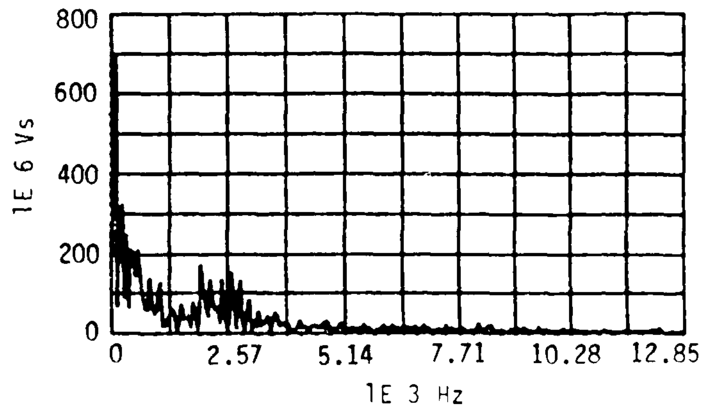
b. Magnitude Component of Transformed Signal.

c. Decibel Representation of Magnitude Component.

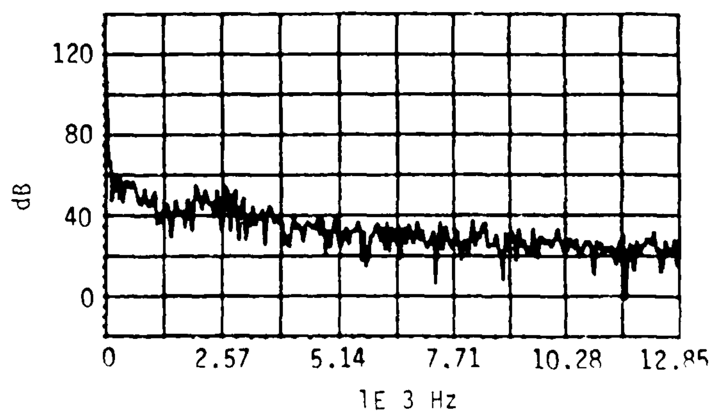
Figure 13. Frequency Analysis of Noise 3 Feet from Printer.



a. Sampled Signal.



b. Magnitude Component of Transformed Signal.



c. Decibel Representation of Magnitude Component.

Figure 14. Frequency Analysis of Noise at Corner of Room.

K was determined experimentally for the sensitivity setting of the B & K microphone used during recording and data sampling rate used in the spectral analysis (see Appendix C). The noise sample shown in Figure 13 was taken 3 feet from an operating printer with the printer hood open. The sample shown in Figure 14 was taken approximately 12 feet away in the corner of the room under the same conditions. These examples were some of the highest sound levels recorded. The B & K meter, in the linear filter mode, indicated 79 decibels near the printer and 73 decibels in the corner. The B & K noise meter readings at the 17 locations monitored ranged from 68 decibels to 79 decibels with a mean value of 72 decibels. Figures 13 and 14 are typical of the spectral distribution near and away from noise sources (printers, card readers, and so on). Away from noise sources, the highest sound levels are concentrated below 600 hertz. This level decreases rapidly between 600 hertz and 1200 hertz and more gradually beyond 1200 hertz. Near (several feet) strong noise sources, the sound level remains high out to approximately 6000 Hz and sound levels at all but the lowest frequencies are higher.

There are no apparent gaps in the noise spectrum of the computer facilities tested which would favor one alarm frequency over another. At higher frequencies less background noise is present. However, the high frequency sound attenuates more rapidly than those at the lower frequencies. In the frequency range between 2500 and 3000 hertz noise spectrum data indicated that background noise would not exceed 70 decibels at distances greater than 6 feet from strong noise sources. The acoustic receiver tests indicated that a threshold value of 80 decibels was necessary to eliminate false alarms at a distance of 5 feet from a large open printer. No false alarms were recorded at the 70-decibel setting when the printer cover remained closed during operation.

Category I: Exploratory/Environmental -- Exploratory Design Tests

These tests provided a means of rapidly checking the feasibility of design concepts (components or systems) and discovering unforeseen effects. The results of these tests were used to refine designs and test procedures in Category II and Category III testing.

During these tests laboratory models were exposed to real world conditions, and their responses were monitored. The video recorder and other apparatus appropriate to a particular test were used to monitor and document the tests for repetitive reviews and evaluations.

Crude extinguishers constructed of brass tubing, compression fittings, and fusible alloy sealed discharge ports (Figure 15) were placed in waste receptacles, and their performances during actual waste receptacle fires were monitored. More sophisticated extinguisher and extinguisher/alarm units were also tested in the same manner. Fusible alloy melting temperature, agent type and quantity, exit port sizes, number of ports, and orientation of the ports were tested. These tests were conducted during the same period as the initial temperature-versus-time tests and provided valuable insight into the nature of waste receptacle fires and extinguisher performance. The fusible alloy plugs respond slowly in massive containers and when in contact with the extinguishing agent. Reaction forces on the extinguisher during agent release are significant and scattering of burning material from the waste receptacle is possible if agent discharge rates are too high. The fire will not be suppressed and agent decomposition will increase if the discharge rate is too slow. In general, both Halon 2402 and 1211 will extinguish waste receptacle fires effectively once release occurs. However, during one test where Halon 2402 was delivered to the fire through a tube from an externally mounted container, i.e., the Halon was not heated prior to release, the liquid Halon 2402 ran down the side of the waste receptacle without vaporizing and did not extinguish the fire, thus reenforcing the selection of Halon 1211 as the primary extinguishing agent.

Freon-driven air horns (Figure 16) were tested to determine approximate frequency range and signal strength using the B & K sound meter. These horns were also tested using Halon 1211 as the driving gas. Attempts to extinguish a fire using Halon 1211 indicated that the agent discharge rate through even a large horn was too slow to build adequate agent concentration for fire extinguishment. The results of this test suggested that a single discharge for fire suppression and alarm using a vibrating diaphragm horn was not feasible.

A valve (Figure 17) designed to release a single vaporizing liquid agent to separate alarm and extinguisher ports was tested. Short alarm signal duration and two-phase flow through the alarm horn were determined to be a significant problems with this concept.

Fiaure 15. Preliminarv Test Extinouisher.

Figure 16. Freon Horns.

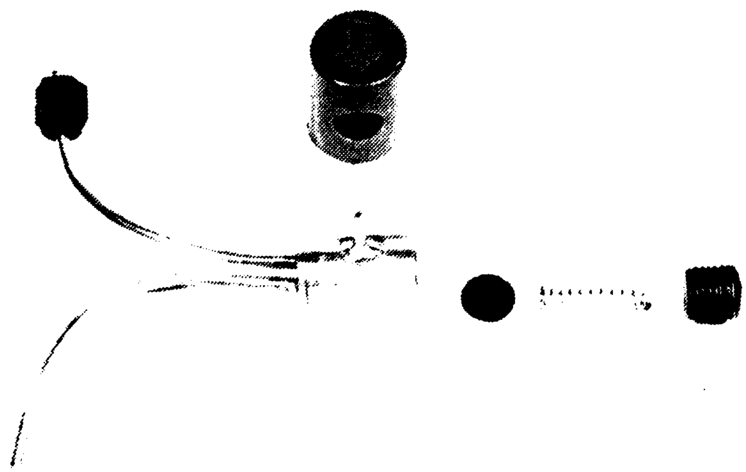


Figure 17. Single Fluid Test Valve.

Several whistles, a sonic converging-diverging nozzle, and vibrating diaphragm horns were compared. Gas flow rates necessary to produce comparable sound levels with the converging-diverging nozzle and whistles were much higher than with the vibrating diaphragm horn, although the driving pressure required was lower. This indicated that the vibrating diaphragm horn was the best alarm choice to be driven by a vaporizing liquid which produces a relatively high pressure for long periods of time.

Category II: Component Tests-- Fusible Alloy

The purpose of this test was to evaluate the performance of various fusible alloy designs. The results of this test and the vaporizing liquid sensor test were used to select the best release mechanism for the SAFE CAN.

Twelve fusible alloy configurations were tested in a controlled-temperature environment using a small convection oven heat source. Response times were recorded for each configuration. Pressure within the SAFE CAN was measured during selected tests. The parameters studied during these tests included the environment temperature (i.e., the temperature to which the fusible alloy is exposed), the fusible alloy melting temperature, the fusible alloy hole size, the number of fusible alloy seals, and the highly conductive/convective mass adjacent to the fusible alloy.

Seventy-five tests were performed. Figure 18 shows the convection oven and thermocouple temperature sensor apparatus used for these tests. The fusible alloy configurations tested are presented in Figures 19 through 22. Figure 19 shows two thin-walled and five thick-walled fusible alloy sealed containers. Six containers have three fusible alloy plugs; the seventh has five. Hole sizes of 1/64, 1/16, and 1/8 inch are represented. These units were tested at oven temperatures of 200°F, 300°F, and 400°F. Fusible alloy melting temperatures of 117°F, 136°F, 158°F, and 255°F were used. The containers were either completely filled or contained 10 milliliters of Halon 1211.

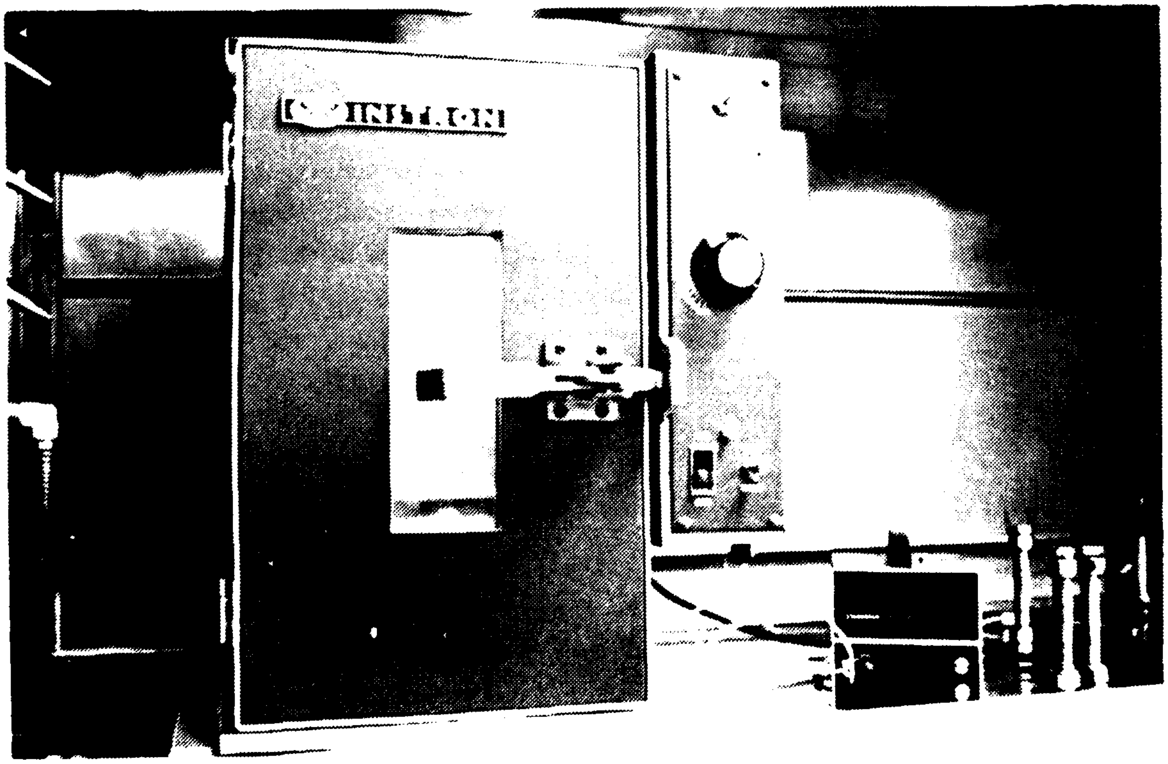


Figure 18. Fusible Alloy Test Apparatus.

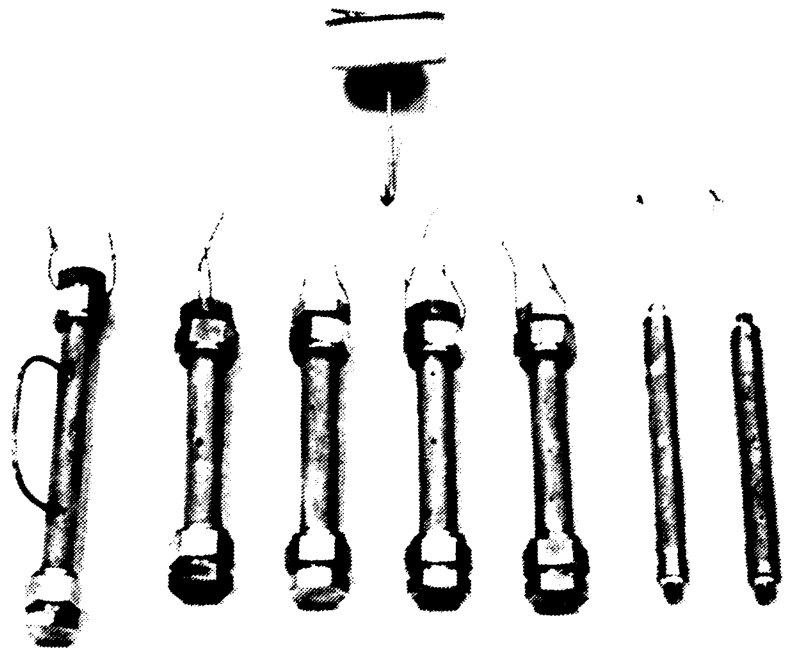


Figure 19. Fusible Alloy Sealed Containers.

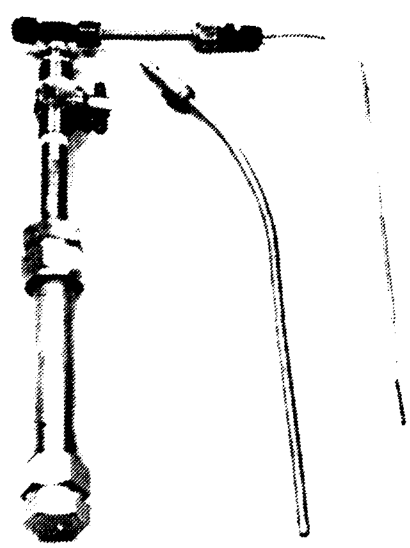


Figure 20. Fusible Alloy Extension Tubes.

Figure 21. Fusible Alloy Isolation Configuration.

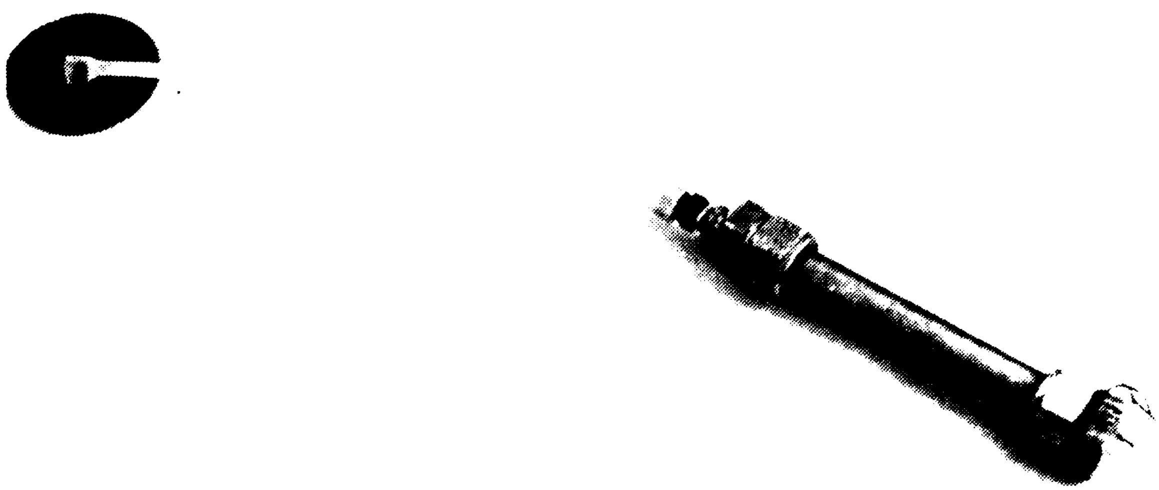


Figure 22. Plastic "Fusible Alloy."

Figure 20 shows two copper tube extensions that were tested. Both tubes are 12 inches long; one is 1/8-inch tubing and the other is 1/4-inch tubing. The end of the tube away from the container was sealed with the fusible alloy. The same oven temperatures and fusible alloy melting temperatures as used with the alloy sealed containers were used in this test. The tube adjacent to the fusible alloy contained either liquid or vapor states of Halon 1211.

Figure 21 shows the three fusible alloy isolation configurations tested. The container on the left uses a copper-clad plastic board to insulate the fusible alloy from the conductive mass of the container. The short length of tubing shown in the center contained a fusible alloy plug at one end. The other end was connected to the Halon container by a nylon tube. The compression fitting caps on the right contained a fusible alloy seal and were connected to the Halon container through nylon fittings. Figure 22 shows a plastic "fusible alloy" configuration tested. The nylon tube melts when exposed to high temperatures, releasing the Halon. Limited testing was performed on this unit.

It was expected that response times would increase with higher melting point alloys and lower oven temperatures. It was also expected that the more thermal mass adjacent to the fusible alloy, the slower the response time would be. The number of fusible alloy ports and their sizes was not expected to affect response time. All of these anticipated trends were substantiated by the fusible alloy testing. Two other phenomena were indicated by test results. The ratio of the heated surface area to the mass of the highly conductive material adjacent to the fusible alloy is significant to response time. This was illustrated by the fact that the brass compression fitting caps with fusible alloy seals, having the lowest conductive mass adjacent to the fusible alloy but also having very little surface area through which to absorb heat, had slower response times than the all-metal tube extensions. The other phenomenon indicated that the conductive and convective heat transfer pathways through the metal extension tubes are restrictive enough to allow rapid temperature buildup in the tubes near the fusible alloy tips, providing some of the fastest response times measured.

The fastest response time recorded was 4 seconds. This time was obtained with the thin-walled fusible alloy sealed container containing 10 ml of Halon 1211. The oven temperature was 400°F, and the fusible alloy melting temperature was 117°F. The port farthest from the liquid Halon in the bottom container was the only one that released. Interestingly, when the thin-walled container was completely filled with Halon 1211, it produced some of the slowest response times. For example, at an oven temperature of 200°F and an alloy melting point of 158°F, the filled thin-walled container, weighing 138 grams, released in 4 minutes 40 seconds. The slowest response time recorded was 6 minutes 36 seconds for a completely filled thick-walled container weighing 416 grams at an oven temperature of 200°F and an alloy melting point of 158°F. The tube extensions consistently produced the fastest response times, ranging from 6 seconds at an oven temperature of 400°F and a fusible alloy melting temperature of 117°F to 50 seconds at an oven temperature of 200°F with an alloy melting point of 158°F.

Category II: Component Tests -- Vaporizing Liquid Sensor

The purose of this test was to evaluate the performance of Vaporizing Liquid Sensor (VLS) designs that could be used to activate the SAFE CAN. The results of this test and the fusible alloy test were used in selecting the best sensing mechanism for SAFE CAN. VLS designs were tested in a fixed temperature environment. The parameters investigated included the environmental temperature, the type of sensor fluid, and the sensor volume.

The four sensor configurations tested are shown in Figure 23. The sensors included 10-inch and 20-inch lengths of 1/8-inch copper tubing and 20-inch and 40-inch lengths of 1/4-inch copper tubing all 0.032 inch wall thickness. The sensors contained either Halon 1211 or 2402. The sensors were exposed to convection oven temperatures ranging from 100°F to 240°F. Initially a Bourdon tube pressure gage was connected to the end of the sensor to monitor internal pressure. Later an electronic pressure transducer was used. VLS test data obtained using the Bourdon tube pressure gage illustrate an inherent drawback of the VLS concept. It was expected that the smallest sensor volume would produce the fastest response times and that the internal

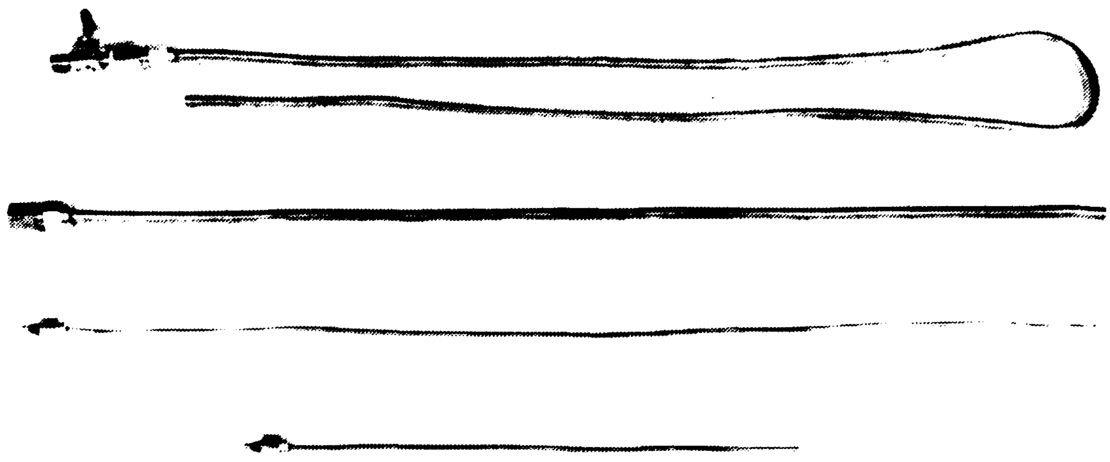


Figure 23. VLS Sensors.

pressure in all sensors would approach the vapor pressure of the sensing fluid at the oven test temperature. With the Bourdon tube pressure gage the largest sensor produced the fastest pressure increase and the highest peak gage pressure of 10 lb/in^2 (22 lb/in^2 absolute). This highest peak pressure is well below the anticipated vapor pressure of 55 lb/in^2 absolute for Halon 2402 at 200°F. Analysis of the results obtained with the Bourdon tube gage indicates that the VLS and Bourdon tube combination appears to act as a heat pipe with the liquid vaporizing in the heated sensor, condensing in the unheated Bourdon tube, and draining back to the sensor. This phenomenon offered a path of very low thermal resistance which rapidly transferred heat energy away form the heated portion of the sensor, reducing the rate of pressure increase and the peak pressure produced. The higher the ratio of heated area (sensor) to unheated area (Bourdon tube) the faster the pressure increase and the higher the peak pressure; thus the superior performance of the largest sensor.

Although the unheated area was reduced in testing by using an electronic pressure transducer, the potential problem of reduced VLS performance due to partial heating would remain in any VLS used to activate a SAFE CAN.

A series of VLS tests was conducted using a Kulite model XST 190 electronic pressure transducer to monitor internal sensor pressure. The electronic transducer reduced both the unheated portion of the VLS/ pressure sensor system and the quantity of air trapped above the sensing fluid. Tests were performed using the 10-inch by 1/8-inch tubing and 20-inch by 1/4-inch tubing VLSs. Both sensing fluids, Halon 1211 and 2402, were tested. Oven temperatures from 100°F to 200°F were applied. The quantity of sensing fluid and the fraction of the sensor exposed to heating were also varied.

The results of this testing were generally as expected. Halon 1211 produced larger pressure increases in shorter periods of time than did the Halon 2402 (19 lb/in^2 in 15 seconds versus 11 lb/in^2 in 40 seconds in a 200°F test using the 1/4-inch tubing sensor). However, Halon 1211 produces significant pressure increases during long-term exposure to low temperatures (28 lb/in^2 in 8 minutes at 100°F versus a maximum pressure increase of 5 lb/in^2 for Halon 2402). When the entire VLS was exposed to heating, pressures in all sensors approached the vapor pressure of the sensing fluid at the oven temperature being tested. The 1/8-inch tubing sensor consistently produced peak pressures a few pounds per square inch lower than the 1/4-inch tubing sensor. This can be attributed to the lower heat absorption area for the 1/8-inch tubing sensor coupled to the small fixed-heat rejection area of the pressure transducer and coupling. Another anomaly occured when the 1/4-inch tubing was filled to 80-percent capacity with Halon 2402 and heated to 200°F. The peak pressure exceeded the vapor pressure of the sensing fluid. The measured pressure was consistent with the pressure that would be produced by the compression of the air over the sensing fluid as the fluid expands during heating. The less mass associated with the VLS--smaller size and lower fill percentage--the faster the initial rate of pressure increase. The 1/8-inch tubing sensor with a 50-percent fill exceeded a 10 lb/in^2 pressure increase in 20 seconds versus 25 seconds for the 1/4-inch tubing with a 50-percent fill versus 35 seconds for the 1/4-inch tubing with an 80 percent fill (all at 200°F). The response of the small sensor was effected much less by partial heating of the sensor than was the large sensor. Response of the 1/8-inch tubing sensor inserted half-way into the oven was nearly identical to the response of the same sensor when completely inserted into the oven for the first 50 seconds. The 1/4-inch tubing sensor inserted halfway into the oven responded much slower than when completely inserted (42 seconds to exceed 10 lb/in^2 versus 25 seconds).

Based on these results and observations--the good performance achieved with the fusible alloy sensors and the added complexity and cost of the VLS release mechanism--the fusible alloy sensor was selected for use in the SAFE CAN.

Category II: Component Tests -- Acoustic Coupling

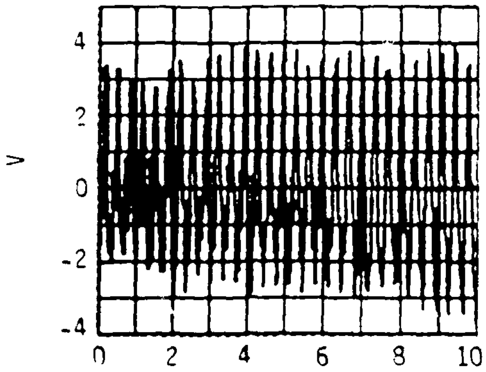
The purpose of this test was to develop the proposed acoustic coupling and to further define the acoustic coupling requirements.

Signals from candidate acoustic transmitters were measured and compared to measured environmental noise levels to determine the best method of descrimination. Frequency and decibel levels were measured, using Fourier spectrum analysis. ,The effects of separation distance between transmitter and receiver, orientation of transmitter and receiver, and acoustic environment were studied.

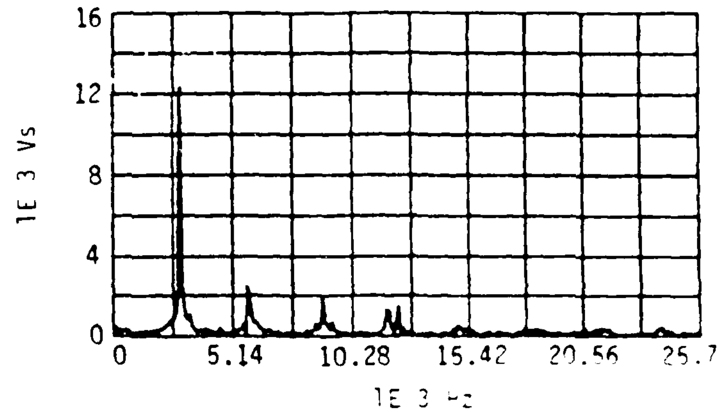
Preliminary measurements of sound levels produced by five candidate Freon-driven air horns within octave bandwidth were made using the B & K sound meter. Measurements were taken at 10 feet and 20 feet from the horns. Angles on-axis and 45, 90, 270, and 180 degrees off-axis from the horns were tested. The three largest horns were manufactured by Falcon Safety Products. The smaller horns were manufactured by Peterzell Co., and Qualco Products Co. Based on these preliminary results, the three smallest horns were selected for detailed analysis. A flowmeter and pressure gage were connected in line between the Freon gas source and the horns. The acoustic signals produced by each horn at a range of pressures and flow rates were recorded using the B & K sound meter and the Ampex recorder. The microphone was located 3 feet from the horn being tested. Recordings were also made at several distances from the horn of the signals produced by the small horns using Halon 1211 as the driving gas. The Tektronix signal processing system was used to perform a Fourier transform and produce frequency distribution plots for each recorded signal. An alarm receiver design was developed based on the results of this testing. This design was fabricated and tested at CERF and at the UNM computing center to verify that it could recognize the alarm signal.

Results of the preliminary testing indicated that all five air horns could produce sound levels significantly higher than the background noise. Maximum signal levels ranged from 106 decibels in the 100-hertz octave bandwidth for the largest horn to 85 decibels in the 400-hertz octave bandwidth for the smallest horns. Off-axis sound levels dropped only 2 decibels for the smallest horns. The pressure and flow rate tests showed that the fundamental frequency produced by each horn was insensitive to changes in pressure and flow rate. This is a very desirable feature from the standpoint of alarm detection. The peak sound level produced at the fundamental frequency fluctuated several decibels from sample to sample and, in some samples, completely disappeared momentarily even though flow rate and pressure remained constant. The average peak level of the fundamental frequency tended to decrease with pressure and flow rate. Freon 12, with its higher vapor pressure, was capable of producing slightly higher maximum decibel levels than were possible with Halon 1211; however, at the flow rates required to provide a sustained signal Halon 1211 produced the same decibel level signal and tended to cool due to less rapid vaporization, providing a longer signal duration. The fundamental frequency of a horn driven by Halon 1211 was 200 to 300 hertz lower than when the same horn was driven by Freon 12. The fundamental frequencies of the two small horns ranged from 2400 hertz to 2800 hertz, depending on the particular horn and the driving vapor. The large Falcon Safety Products horn produced a fundamental frequency of 830 hertz but the first harmonic at 1600 hertz generally dominated the signal.

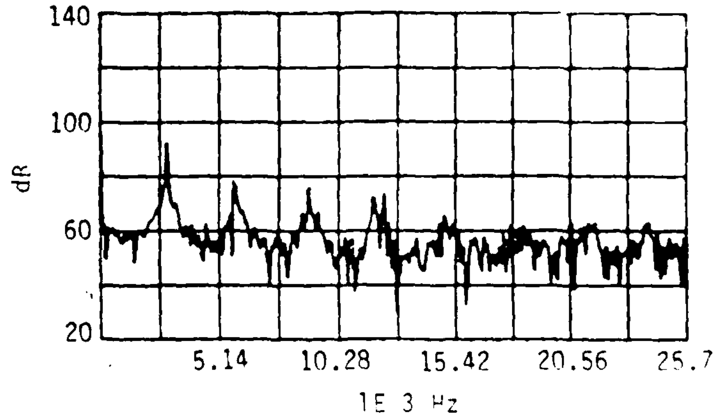
Figure 24 shows the frequency distribution plots generated by the Tektronix signal processing system for a sample of the signal produced by the small Peterzell Co., horn driven by Halon 1211. The recorder microphone was 19 feet from the horn in an open, 10- by 20-foot room. Note that the signal



a. Sampled Signal.



b. Magnitude Component of Transformed Signal.



c. Decibel Representation of Magnitude Component.

Figure 24. Frequency Analysis of Small Horn Signal.

is significantly stronger, more than 10 decibels, than the background noise at the 2500 hertz indicated in Figures 13 and 14. As with the plots of computer facility noise, the three graphs show the signal sampled, the magnitude component of the transformed signal, and a decibel representation for the magnitude component. These results indicated that the signal could be distinguished from background noise in computer facilities based on signal frequency, intensity, and duration with an allowance for momentary loss of the fundamental signal.

Laboratory model receivers were fabricated and tested both at CERF and at the UNM computing center. The center frequency of these units was matched to Qualco Products Co. horns at 2650 hertz. The duration of signal required was 20 seconds, with no loss of signal greater than 1/4 second. Results of this testing showed that the sonic alarm could consistently be detected, based on frequency, intensity, and duration criteria. The maximum allowable distance between the alarm and receiver depended primarily on the receiver's intensity threshold and the acoustic environment in which the system was operating. In a large open warehouse (metal and concrete walls and floor) the alarm was detected from distances of more than 30 feet with an intensity threshold of 71 decibels. When the alarm was rotated 90 degrees from the axis of the detector microphone, the distance did not change. With an intensity threshold of 76 decibels the alarm could only be detected reliably from a distance of 20 feet. The threshold decibel levels indicted here are fairly conservative (roughly 2 decibels) because they represent the apex of a parabolic signal detection region characteristic of the phase-locked loop tone detector chip used in the receiver units. During testing it was determined that the receiver required a bandwidth of approximately 200 hertz to reliably detect the alarm signal produced by the air horn. The bandwidth of the detector region increases to 200 hertz at 2 to 3 decibels above the minimum threshold indicated at the center frequency of the receiver. Suggestions for making the frequency and intensity detection zone more rectangular are presented in Appendix B.

Testing in the UNM computing center indicated the alarm could consistently be detected at a distance of 25 feet from the receiver microphone with a receiver intensity threshold of 71 decibels. This threshold setting did not generate false alarms if the receiver microphone was located more than 10 feet from loud noise sources such as printers. The UNM computing center printer room is approximately 40 by 30 feet with a 16-foot ceiling. An alcove approximately 40 by 20 feet with an 8-foot ceiling adjoins the printer room on one side. The temperature in the printer room was between 68°F and 72°F during testing.

Category II: Component Tests — Agent Discharge

The purpose of these tests was to evaluate the effectiveness of the Halon extinguishing agents and the modes of delivering the agent to the fire. The results of these tests were used to determine the quantity of extinguishing agent required and the location, quality, and rate at which it is released.

Tests were performed on waste receptacle fires, using Halon 1211 delivered to the fire through extension tubes. The test extinguisher is shown in Figure 25. The extension tubes used were either 1/8-inch or 1/4-inch OD copper tubing, 12 inches long. The extinguishing agent was directed horizontally around the circumference of the waste receptacle, at an angle 45 degrees downward from horizontal, or vertically down the wall of the receptacle. The agent was released either a fixed-time interval after the temperature at the rim of the receptacle exceeded a set value, 200°F or 300°F, or after the peak temperature had been reached. The agent was released in either a vapor state or in a primarily liquid state. Additional tests were performed in waste receptacle fires using the thin-walled fusible alloy sealed containers and an externally mounted combined extinguisher and alarm test unit (Figure 26). These tests evaluated both Halon 1211 and Halon 2402. Release was accomplished by the heat of the fire acting on the fusible alloy seals. Another test series was performed in the laboratory to accurately measure the discharge rate of liquid Halon 1211 through restricting orifices of different sizes.

Results of the fire tests showed that release of Halon 1211 in the vapor state was not desirable. The high volumetric vapor flow rate required to rapidly build Halon concentration to extinguish crumpled paper fires blew burning paper from the waste receptacle. Even when discharged at this high

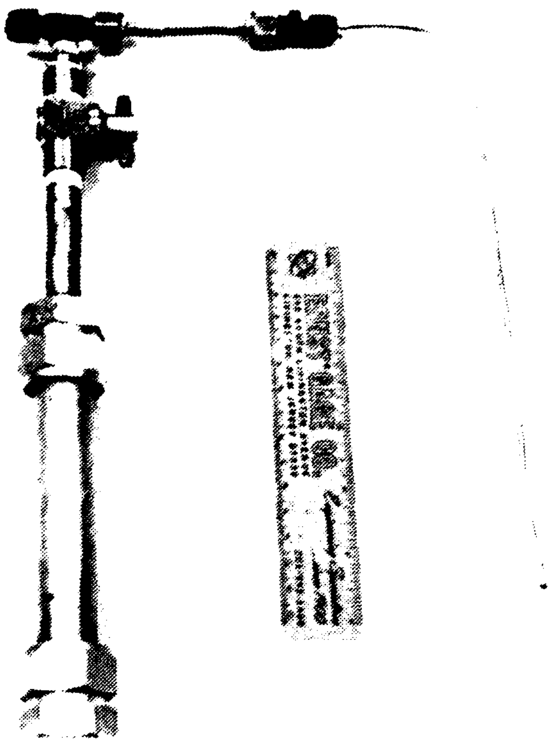


Figure 25. Agent Discharge Test Extinguisher.

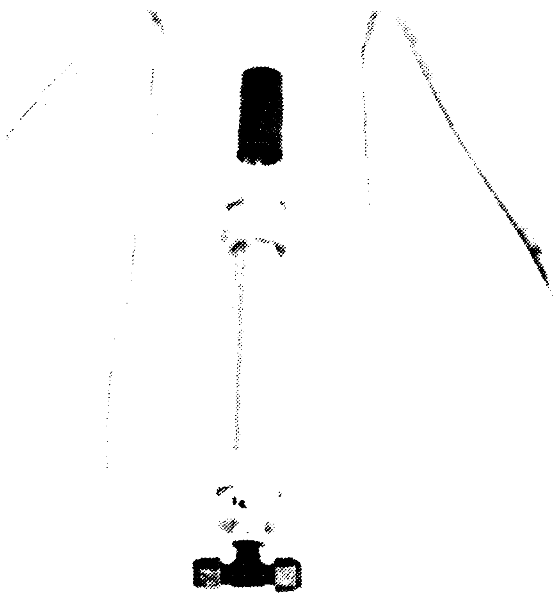


Figure 26. First Combined Extinguisher/Alarm Unit.

flow rate and directed toward the bottom of the receptacle the Halon 1211 vapor did not extinguish a deep-seated paper ream fire. Liquid Halon 1211 worked very well. Discharge rate is still important because too high a rate blows ashes and burning paper out of the receptacle, while too slow a discharge rate does not produce sufficient Halon concentration to extinguish the fire before the Halon is carried off by convection. Discharge of 40 milliliters (73 grams) of Helon in 5 seconds appeared to be the maximum allowable discharge rate when the discharge is directed downward approximately 45 degrees from horizontal along the wall of the waste receptacle. Discharge of the same quantity of Halon in 20 seconds appears to reduce effectiveness. A 1/16-inch diameter, 1/4-inch long restrictive orifice at the end of a 1/4-inch OD tube produces the desired flow rate. During this testing, 30 milliliters (55 grams) of liquid Halon 1211 delivered in less than 20 seconds proved adequate to extinguish all of the fires tested in the large 20-gallon waste receptacle. The 30 milliliters of Halon 1211 in the 20-gallon waste receptacle corresponds to a 10-percent design concentration.

Category III. Initial system testing-- Extinguisher Alarm Subsystem

The purpose of these tests was to verify that the integral extinguisher/alarm subsystems performed as desired and to provide an opportunity to make final refinements. Combined extinguisher and alarm models, including container, agent, release mechanism, and alarm, were tested first in a laboratory environment and then in waste receptacle fires. Significant aspects of performance were monitored.

The first combined extinguisher/alarm subsystem tested is shown in Figure 26. An exploded view of the container, piston, and valve mechanism is shown in Figure 27. The unit used a single container, divided into two compartments by a sliding piston, to contain Halon 1211 extinguishing agent and alarm vapor source. The container was 7/8 inches in diameter and 6 inches long. The container cap held a rubber washer which sealed both the container cap and the sliding shaft valve. A Qualco Products Co. horn was attached to the top end of the sliding shaft valve; the other end was attached to the

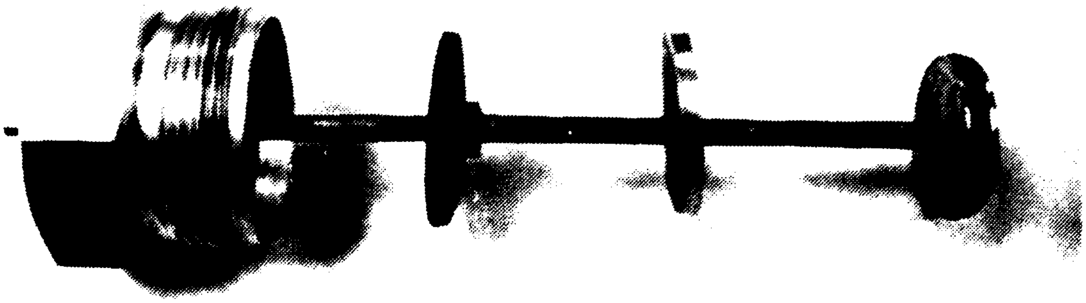


Figure 27. Piston and Valve Mechanism.

piston. An O-ring sealed the piston to the container wall. Two extension tubes, approximately 16 inches long, lead from the bottom of the container to the rim of the waste receptacle where the tubes curved downward into the receptacle. Fusible alloy plugs sealed the ends of the tubes.

Tests in the laboratory, where the extension tubes were replaced by a valve, verified that the coupling mechanism and alarm valve worked as planned. Tests were then performed in waste receptacle fires. Extension tubes measuring 1/8 and 1/4 inches in diameter were tested with 117°F and 158°F fusible alloy seals. In most of the tests the unit performed very well. Extinguishing agent release occured 10 to 30 seconds after the temperature at the top of the receptacle exceeded 200°F. The alarm usually functioned, lasting from 30 seconds to more than 2 minutes. On all but two occasions the fire was extinguished. The following observations were made during these tests. The discharge orifice had not been properly sized (these tests were conducted prior to the discharge orifice sizing tests). On one occasion the reaction force of the agent discharging through the 1/4-inch tubing lifted the extension tube out of the waste receptacle and the fire was not extinguished. On another occasion the discharge through the 1/8-inch tubing was so slow that the fire was not extinguished.

The natural rubber used for piston O-rings and valve seals was attacked by the Halon 1211. This had been expected. Compatible gasket material had not been available for these preliminary tests. The deterioration of the seals prevented proper sealing of the piston and valve and caused binding of the moving parts. These problems occurred only after two or three tests had been performed using the same seals. However, this indicated a potential problem of elastomer seals and sliding surfaces which are exposed to Halon 1211 for long periods of fire.

The sonic alarm also suffered from repeated exposure to the Halon. The plastic diaphragm in the horn accumulated an oily film and lost tension, causing the alarm to fail after four or five tests. The alarm deterioration may also have been caused by repeated assembly and disassembly. This presented a problem for repeated testing of individual units but would not be significant in the one-time operation planned for production units.

The Halon filling procedure presented problems because the compartments had to be filled sequentially and the fill of each compartment could not be measured separately. The combined weight of the Halon in both compartments ranged from 67 g to 86 g. No check of extinguisher and alarm charge level other than total unit weight was provided.

Despite the problems just discussed, the concept had been verified. The fusible alloy seal located remotely from the extinguishing agent container, via extension tubes, responded well in real fire environments. The extinguishing agent, Halon 1211, was very effective in all types of receptacle fires tested. Both extinguisher and alarm were actuated by a single sensor. The alarms functioned reliably the first time they were tested. The unit was relatively simple, compact, and durable.

The subsystem design was modified to eliminate the problems encountered during the first series of tests. In this second design the sliding piston was replaced by a flexible diaphragm. The sliding shaft valve was replaced with a cone, seating against an O-ring. Separate filling ports were provided for each compartment and an optical fill level indicator was provided for the alarm-driving fluid compartment. A single extension tube was used to make the unit more compact. A restrictive orifice was formed at the exit of the extension tube. Implementation of these changes required component testing of diaphragm and valve designs and materials. The resulting design and subsystem model became the final SAFE CAN design and subsystem prototype. A photograph of the prototype is shown in Figure 28. The design drawings and description are presented in Section IV. Laboratory tests were performed to verify proper operation of the new units. The first fire tests with the new subsystem were performed in conjunction with the alarm receiver and are discussed in the following paragraphs.

Category III: Initial System Testing — Total System

Purpose of these tests was to verify that a completely integrated SAFE CAN system would perform as desired. The total SAFE CAN system consists of the extinguisher/alarm unit plus a remotely located alarm receiver unit. This testing was also to indicate any final system design modifications that might be required prior to System Evaluation Tests. No modifications were indicated by this testing, so these tests were also included in the system evaluation.

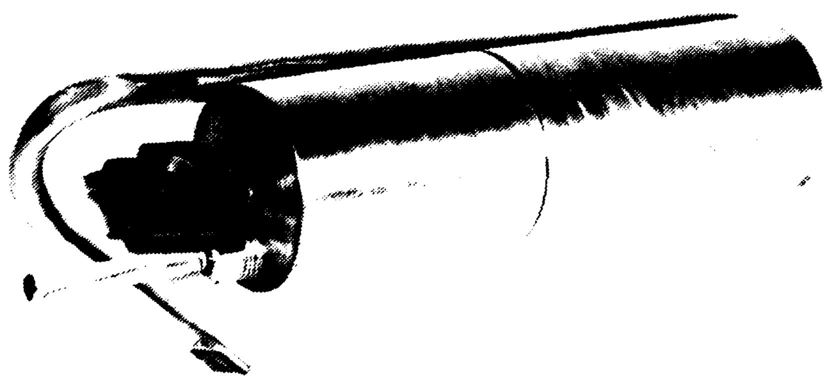


Figure 28. SAFE CAN Prototype Without Cover.

Six tests were performed on paper fires in large and small waste receptacles. Two large and one small (two extinguishing agent compartment volumes) SAFE CAN prototypes were tested. In all cases the fire was extinguished. Response time, measured from the time the first rim temperature exceeded 200°F until agent release, ranged from 25 to 40 seconds with an average of 32 seconds. In two cases the sonic alarm failed. The first failure was caused by faulty fabrication of the SAFE CAN. The second failure was due to reuse of the damaged horn. In all cases where the sonic alarm on the SAFE CAN functioned properly, the receiver unit detected the signal and activated an electronic alarm representing the permanent building alarm system to the local fire department.

Category IV. System evaluation tests-- Primary System

The purpose of these tests was to extensively test the primary SAFE CAN design prototype to determine reliability and accomplishment of design and performance objectives. A series of 47 fire tests of the recommended SAFE CAN design prototypes, including 5 tests using Halon 2402 as the extinguishing agent, was performed. Temperature, response time, fire extinguishment, alarm duration, and signal detection were recorded. The fire fuel loads included crumpled paper, ream paper, cloth, and cloth plus alcohol. The alarm and receiver separation and orientation was varied as much as possible within the fire test area.

The flaming fire was knocked down in all test cases. Complete extinguishment was accomplished in 42 of the 47 tests. In the remaining five cases all deep-seated ream paper or cloth fires, the fuel continued to smolder after the flames had been suppressed. Measured response times after the first sensor exceeded 200°F ranged from 0 to 105 seconds with an average of 34 seconds.

In 11 of the tests the sonic alarm failed to operate properly. In all but three of these 11 tests the alarm had been used two or more times prior to failure. In the cases where a new alarm failed, the SAFE CAN had been exposed to low temperatures before the test and the liquid inside the SAFE CAN failed to vaporize. In all cases where the alarm was new and the ambient temperature was above 60°F, the alarm functioned properly and the receiver detected the signal. Alarm duration ranged from 0 seconds to 420 seconds.

Category IV: System Evaluation Tests -- Toxicity

The purpose of these tests was to quantitatively measure the concentrations of toxic gases produced during fire extinguishment using SAFE CAN. Previous investigations (Reference 1) had suggested that dangerous concentrations of toxic gases would not be produced using the Halon extinguishing agents. The results of this testing would either support or contradict this judgment for the actual fire extinguishment situations.

Tests were conducted in sealed rooms with volumes of 248 ft^3 and 968 ft^3. Mine Safety Appliances Co. (MSA) Samplair pumps and MSA detector tubes were used to sample and measure concentrations of gases within the test volume. A thermocouple located adjacent to the detector tubes measured the temperature of the sampled gases and an oscillating fan was used to mix the gases, producing a uniform distribution within the test volumes.

The following procedure was used in conducting the toxicity tests. A waste receptacle with fuel load and attached SAFE CAN was located near the center of the test volume. The fuel load was ignited and the door to the test volume was sealed. Agent release was detected acoustically from outside the test volume. After agent discharge was completed the oscillating fan was activated and the gases were allowed to mix for 1 minute or until the temperature inside the test volume decreased to a value within the calibrated range of the detector tubes, whichever was longer. Barometric pressure, relative humidity, and temperature sampling were conducted through a sampling point 5 feet above the floor of the test chamber using an extension tube that extended 3 feet into the chamber. The indicated concentrations were recorded and then corrected for temperature, relative humidity, and pressure, and normalized to a uniform concentration in a 1000 ft^3 volume.

Tests were performed to measure carbon monoxide (CO), carbon dioxide (CO_2), bromine (Br_2), chlorine (Cl_2), hydrogen chloride (HCl), hydrogen fluoride (HF), and phosgene ($COCl_2$). The CO and CO_2 tests measured concentrations of these gases produced with and without fire suppression. The tests were conducted in the small 248 ft^3 test volume. Small (6-gallon) and large

(20-gallon) waste receptacle fires were examined. Fuels consisted of either paper or cloth. Halon 1211 was used as the extinguishing agent when CO and CO_2 data were acquired. The Br_2, Cl_2, HCl, HF, and $COCl_2$ tests were conducted on large (20-gallon) waste receptacle fires. Fuels consisted of paper or cloth. Both Halon 1211 and Halon 2402 extinguishing agents were tested.

Several of the detector tubes used in this testing were susceptible to interference from gases other than the gas for which the tubes were calibrated. The bromine and chlorine detector tubes utilize the same chemical reactant and produce the same color change, rendering Br_2 and Cl_2 indistinguishable using these tubes. The Br_2 or Cl_2 concentrations indicated by these tubes would be conservative because the length of the stain produced would be the additive effect of the stain produced by Br_2 and the stain produced by Cl_2. Unfortunately both tubes also react strongly with chlorine dioxide (ClO_2) which produces a stain of a different color and masks the Br_2 and Cl_2 stain. ClO_2 was present in sufficient quantity in each of the fires tested to prevent measurement of Br_2 and Cl_2. The HF and HCl detector tubes rely on acid/base indicators to determine concentration. The HF detector tube is more sensitive, requiring weaker acid to produce a stain than is needed in the HCl detector tube. The HF detector tube is susceptible to interference from other acids including HCl and HBr, while the HCl tube is only susceptible to interference from other strong acids such as HBr. Again the interference is cumulative, producing conservative readings (higher indicated concentrations than are actually present) for the gas being measured. No interferences for the CO, CO_2, and $COCl_2$ detector tubes were indicated.

Maximum measured concentrations of CO, CO_2, HF, HCl, and $COCl_2$ are shown in Table 2. These values have been normalized to a 1000 ft^3 (10 by 12.5 by 8 feet) volume for comparison purposes. The accuracy of these measurements is not great, ±35 percent or better, but is adequate for the purpose of this experiment. Bromine and chlorine could not be measured due to interference from chlorine dioxide. The HF and HCl values should be conservative, due to the additive interference of these two acids and, possibly, HBr. Table 2 shows that the maximum measured concentrations were much lower than the Approximate Lethal Concentration for 15-minute exposure (ALC-15) (Reference 3) for these gases. Although the maximum measured concentrations for a 1000 ft^3 room were somewhat higher than the Threshold Level Value (TLV) (Reference 4) for 8-hour exposure for all gases except phosgene, the results support the prediction that the concentrations of toxic gases produced by SAFE CAN would not be dangerous for short exposure periods. As Table 2 indicates, no phosgene ($COCl_2$) was detected during testing and CO and CO_2 levels were lower with suppression than without. The fact that a stain was produced in the HCl detector tube when Halon 2402, which contains no chlorine atoms, was used as the extinguishing agent indicates that HBr is probably present.

TABLE 2. COMBUSTION PRODUCE CONCENTRATIONS

Compound	ALC-15,[a] ppm	TLV,[b] ppm	Fuel	Maximum Measured Concentration,[c] ppm	
CO	2000[d]	50	paper	774	unsuppressed
				103	suppressed
			cloth	452	unsuppressed
				75	suppressed
CO_2	120,000[e]	5000	paper	4762	unsuppressed
				4390	suppressed
			cloth	7526	unsuppressed
				1505	suppressed
HF[f]	2500	3	paper	12	Halon 1211
				8	Halon 2402
			cloth	36	Halon 1211
				37	Halon 2402
HCl[g]	4750	5	paper	5	Halon 1211
				6	Halon 2402
			cloth	13	Halon 1211
				12	Halon 2402
$COCl_2$	100-150	0.1	all	0	

[a]Approximate Lethal Concentration for 15-minute exposure; Reference 3.
[b]Threshold Level Value, Reference 4.
[c]Normalized to 1000 ft^3 volume.
[d]Fatal in one-half hour, Reference 5.
[e]Death in minutes, Reference 5.
[f]Possible interference from HCl and HBr.
[g]Possible interference from HBr.

SECTION IV
SAFE CAN DESIGN

Based on the problem analysis and testing discussed in the preceding sections a final SAFE CAN design was developed. This design represents a trade-off of response time, reliability, and effectiveness with the constraints of size, durability, and cost.

The SAFE CAN system consists of a capsulized extinguisher and acoustic alarm unit (Figure 29) which is mounted on a waste receptacle, and a wall-mounted acoustic receiver (Fig. 30) which is connected to a central fire alarm system. The SAFE CAN system detects a fire in the waste receptacle, releases and directs an extinguishing agent into the waste receptacle, activates an acoustic alarm, detects the acoustic alarm, and initiates a signal to the central alarm system. A description and discussion of the SAFE CAN components, specifications, cost analysis, and some potential variations on the SAFE CAN design are presented in the following paragraphs.

COMPONENT DESCRIPTION

Figure 31 shows the components of the SAFE CAN extinguisher/alarm subsystem. This unit performs the functions of fire detection, extinguishing agent discharge, local alarm generation, extinguisher alarm coupling, extinguisher and alarm fluid storage, and waste receptacle attachment.

Fire detection is accomplished by means of a fusible alloy seal connected to the extinguishing agent container. The fusible alloy is located in a restrictive orifice at the end of a tube which is open at the other end to the extinguishing agent container. The fusible alloy seal provides a simple, inexpensive release mechanism which eliminates the need for a valve actuating mechanism and potential long-term valve seal and extinguishing agent incompatability problems. This fusible alloy detector configuration consistently produced the fastest or nearly fastest response times during sensor testing. The tubing provides sufficient surface area for heat absorption while restricting both conductive and convective heat transfer away from the fusible alloy. The tubing also allows a location of the fusible alloy detector which is independent of the mounting location of the rest of the subsystem. A detector location 1 inch below the rim of the waste receptacle and 1/2 inch away from

Figure 29. Extinguisher/Alarm Prototype Mounted on Waste Receptacle.

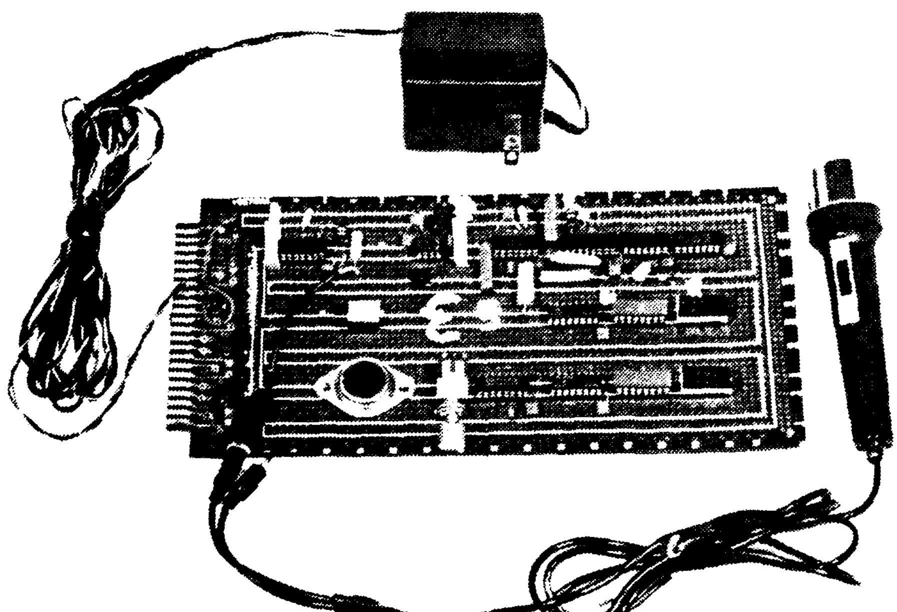


Figure 30. Acoustic Receiver Circuit Board.

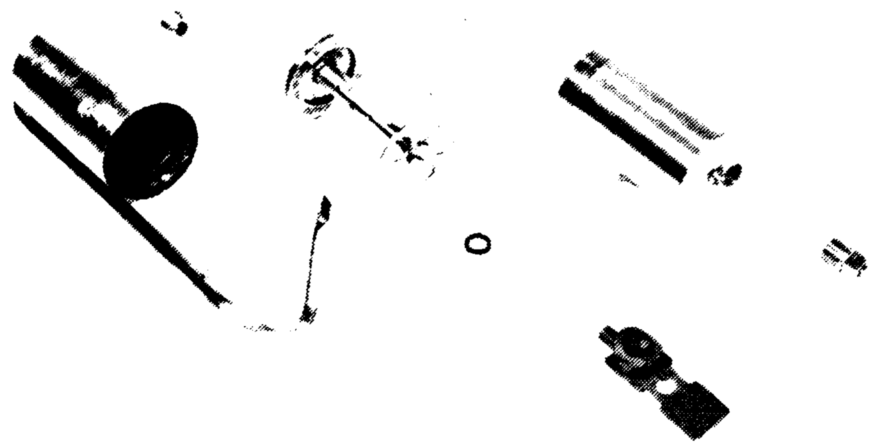


Figure 31. Extinguisher/Alarm Components.

the receptacle wall was selected,based on fire temperature data. A fusible alloy-melting temperature of 136°F was selected as the lowest alloy-melting temperature above the maximum anticipated nonfire environmental temperature.

Extinguishing agent discharge is accomplished through the port vacated when the fusible alloy melts. The liquid extinguishing agent from the bottom of the storage container is carried through the tube to the restrictive orifice. The orifice limits the discharge rate to prevent ejecting ash and burn ing fuel from the waste receptacle. The liquid extinguishing agent discharge was found to be most effective in terms of fire extinguishment during testing The oversize connecting tubing limits head loss between the extinguishing agent storage container and the orifice, thus minimizing the vaporization of the extinguishing agent prior to discharge. The vapor pressure of the extinguishing agent drives the agent from the container through the discharge port

The orientation of the discharge jet is tangential to the wall of the receptacle and angled 30 degrees downward from horizontal. This orientation helps prevent ejection of burning material for the waste receptacle and aids in the distribution and mixing of the extinguishing agent within the receptacle. Extinguishing agent discharge is accomplished in less than 20 seconds in order to build sufficient agent concentration to extinguish the fire before the agent is carried off by the draft of the fire. Halon 1211 is recommended as the extinguishing agent. Halon 1211 has sufficient vapor pressure to drive itself from the storage container, yet emerges from the orifice in a mostly (≈70-percent) liquid phase, allowing it to descend in the receptacle before vaporizing completely and mixing with the combustion process, i.e., the high chemical-radical, flame-holding recirculation zone. No heat from the fire is required to vaporize Halon 1211, once inside the receptacle. This is a distinct advantage over Halon 2402 in this application where the agent may not be aimed directly at the fire source.

The local alarm generated by the extinguisher/alarm unit is produced by a vibrating-diaphragm gas horn. This type of horn produces a loud signal of relatively constant frequency over a wide range of gas pressures and flow rates--desirable features when trying to detect the signal. This type of horn is also well-matched to the vaporizing liquid gas source, requiring higher pressure but lower flow rates than a converging/diverging sonic nozzle or whistle-type acoustic alarms. Halon 1211 is used to drive the horn. A commercially available standard horn with a fundamental frequency of 2650 hertz (when driven by Halon 1211) is used. The acoustic alarm was selected over other types of alarms, e.g., RF, because it was less expensive and could be driven by a compressed or liquified gas, thereby eliminating the need for electrical batteries. Another benefit of the acoustic alarm is that it is audible to personnel working in the vicinity, specifically locating the source of danger.

The extinguisher and alarm are coupled so that the single fusible alloy heat detector activates both. This coupling is sequential in that the fusible alloy heat detector releases the extinguishing agent first which reduces the pressure in the extinguishing agent container, which in turn allows the alarm valve to open. The coupling is accomplished through a flexible diaphragm which separates the extinguishing agent storage compartment from the alarm fluid storage compactment. The diaphragm is acted upon by the vapor pressures of the fluids or each side. When both compartments are sealed, the force acting on the lower surface of the diaphragm is greater than the force acting on the upper surface. This force imbalance is present even though the pressures in both compartments are equal because there is less uncounterbalanced area on the upper side of the diaphragm on which the pressure in the upper compartment can act. The pressure acting on the area of the diaphragm occupied by the valve stem also acts on the underside of the valve, producing zero net force. This maintains the alarm valve in the closed and sealed position. Once the pressure on the lower surface of the diaphragm is removed, as when the extinguishing agent is discharged on a fire, the pressure in the upper compartment forces the diaphragm down, pulling the alarm valve open.

The seal in the alarm-driving agent compartment is formed when the conical end of the valve stem is forced against an O-ring seated in the top of the compartment. The O-ring is made of Viton-A® which is compatible with Halon 1211 and is commonly used in Halon 1211 extinguisher seals. The valve design does not rely on any sliding seals that could bind if O-ring deterioration did occur. This coupling mechanism is simple and durable. It also offers a side benefit in that the alarm will sound if the extinguishing agent is lost through some non-fire-related release, alerting the fire department that the unit must be replaced.

Both the extinguisher and alarm fluids are stored in a single cylindrical container separated into two compartments by the flexible diaphragm. The container is cylindrical to maximize container strength and to utilize economical manufacturing techniques. The container is metal and is compatible with the Halon 1211 fluid. Brass was used during development to allow solder fabrication; however, aluminum or another less expensive Halon-compatible material could be used in manufacturing. The use of separate compartments for extinguisher and alarm fluids allows rapid discharge of the extinguishing agent for effective fire extinguishment and slow alarm fluid discharge to produce a long-duration signal. The separation also allows liquid Halon to be delivered to the fire while vaporous Halon is delivered to the alarm, thereby eliminating the problem of a two-phase flow through the alarm. An optical level indicator extends into the upper alarm compartment. The differences in index of refraction between liquid and vapor Halon produce a dark appearance to the indicator when the liquid level is above the bottom of the indicator and a light appearance when below.

The extinguisher/alarm unit is attached to the waste receptacle so that the entire unit, with the exception of the end of the tube containing the fusible alloy heat detector, is located on the outside of the waste receptacle. The unit is enclosed in a protective plastic cover which is attached to the waste receptacle by a contact adhesive. The protective cover extends over the rim of the waste receptacle and shields the heat detector tube from impact while allowing convective circulation past the tube. The acoustic alarm is integral to the protective cover.

A circuit block diaphragm of the acoustic receiver subsystem is shown in Figure 32. This unit detects and distinguishes the acoustic alarm signal produced by the SAFE CAN extinguisher/alarm subsystem and then triggers a relay which could activate a central alarm system or some other means of telemetry to the fire department.

Three criteria are used for distinguishing the SAFE CAN acoustic alarm from background noise.

1. The signal must be louder than a fixed threshold decibel level.
2. The signal must fall within a narrow frequency range.
3. The signal must be sustained for a set minimum period of time.

An additional condition was included in the design to improve the performance of the unit.

4. The signal is allowed to fail Criteria 1 and 2 for short-time intervals during the longer time interval specified in Criteria 3.

As shown in Figure 32, the acoustic signal is detected by a microphone. The output of the microphone passes through a two-stage amplifier. The combined gain of the two amplifiers determines what minimum signal level will

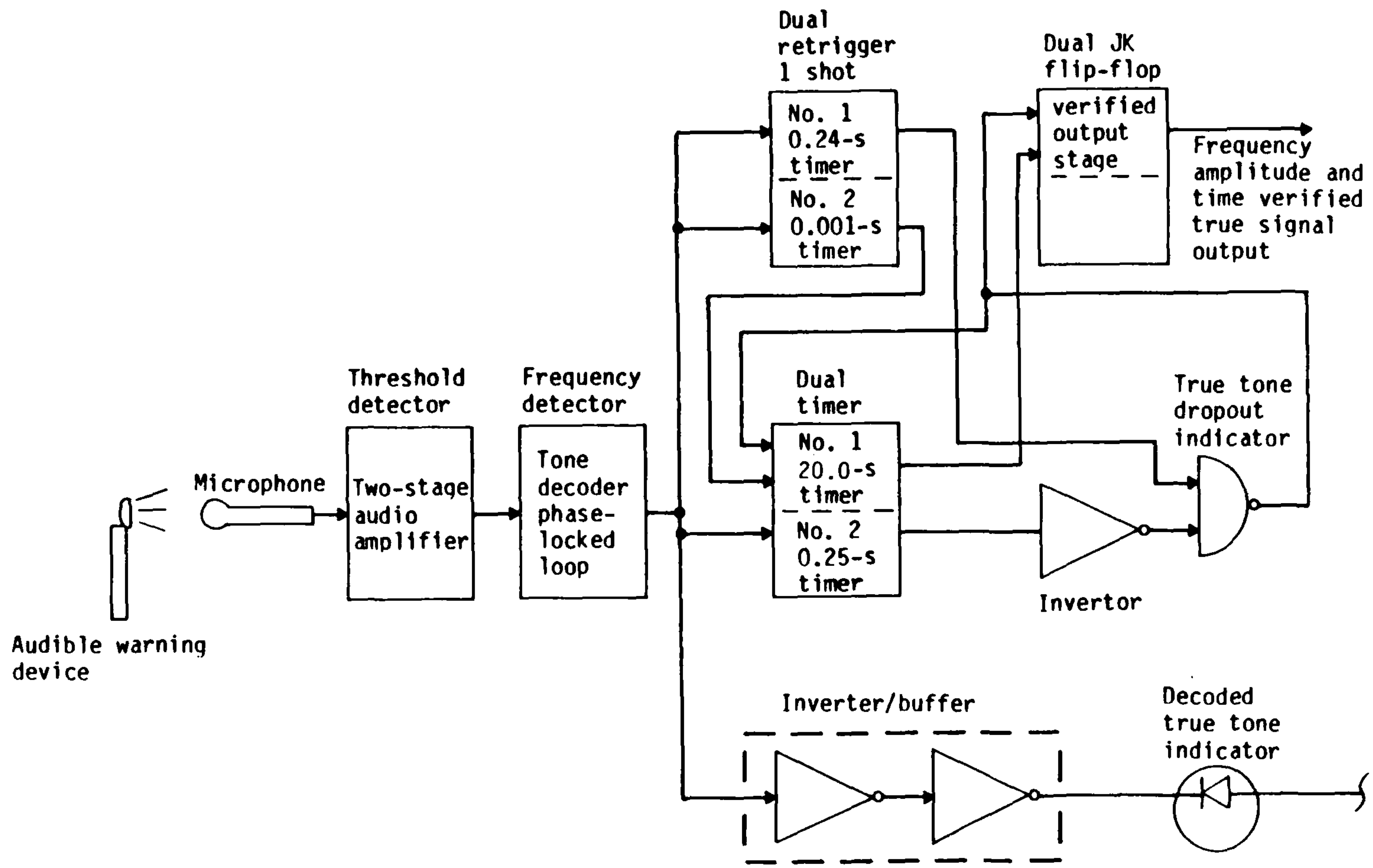


Figure 32. Acoustic Receiver Functional Block Diagram.

activate the tone decoder, thus acting as a signal strength threshold detector. The phase-locked loop tone decoder produces a high or low output voltage state depending on whether the signal frequency falls within the bandwidth of the phase-locked loop. The phase-locked loop acts as an inexpensive analog-to-digital converter, producing a digital true/false output depending on whether the analog input signal does or does not satisfy the first two criteria.

Four timers are used to verify compliance with Criteria 3 and 4. The timers in the dual retrigger one-shot produce true output signals for the time periods indicated in Figure 32 each time the output of the tone decoder changes from false to true. The timers in the dual timer produce a true output signal when a true input signal is received and maintain the true output signal for the indicted period of time (Figure 32) after the true input disappears. These timers do not retrigger during the timing interval. Timer No. 1 of the dual timer requires a true signal at the reset input in order to start timing. If the reset input goes false during the timing interval the timer is reset.

A true output signal from the tone decoder activates the true tone indicator lamp, both retrigger one-shot timers, and the timer No. 2 of the dual timer. The output of timer No. 2 and retrigger one-shot No. 1 are combined in the true-tone dropout indicator, providing a true input reset line of timer No. 1 of the dual timer. The output of retrigger one-shot No. 2 provides a short 1-millisecond pulse input to timer No. 1, starting the measurement of Criteria 3. If the true signal from the tone decoder disappears for a period of time less than the time indicated by timer No. 2, 0.25 seconds, timer No. 2 maintains the true signal to the reset line of timer No. 1. If the output of the tone decoder is false for a longer period of time, timer No. 1 is reset. If the output of the tone decoder switches from true to false and back more than once during the time that timer No. 2 is sustaining the true signal to the reset of timer No. 1 and is false at the end of this period, which would allow the output of timer No. 2 to change to the false, retrigger one-shot No. 1 would sustain the reset input to timer No. 1 in the true state. The actions of timer No. 2 and retrigger one-shot No. 1 satisfy Criteria 4.

One-half of a dual JK flip/flop is used to produce a signal indicating that Criteria 1, 2, 3, and 4 have been met and the SAFE CAN alarm has been detected. A transition of the output from timer No. 1 at the end of the indicated time, 20 seconds, activates the JK flip/flop. A true signal from the true tone dropout indicator must be present at the reset input to the JK flip/flop in order for activation to occur. Thus if timer No. 1 is reset by the output of the true-tone dropout indicator going false before timer No. 1 completes its cycle, the JK flip/flop will not be activated.

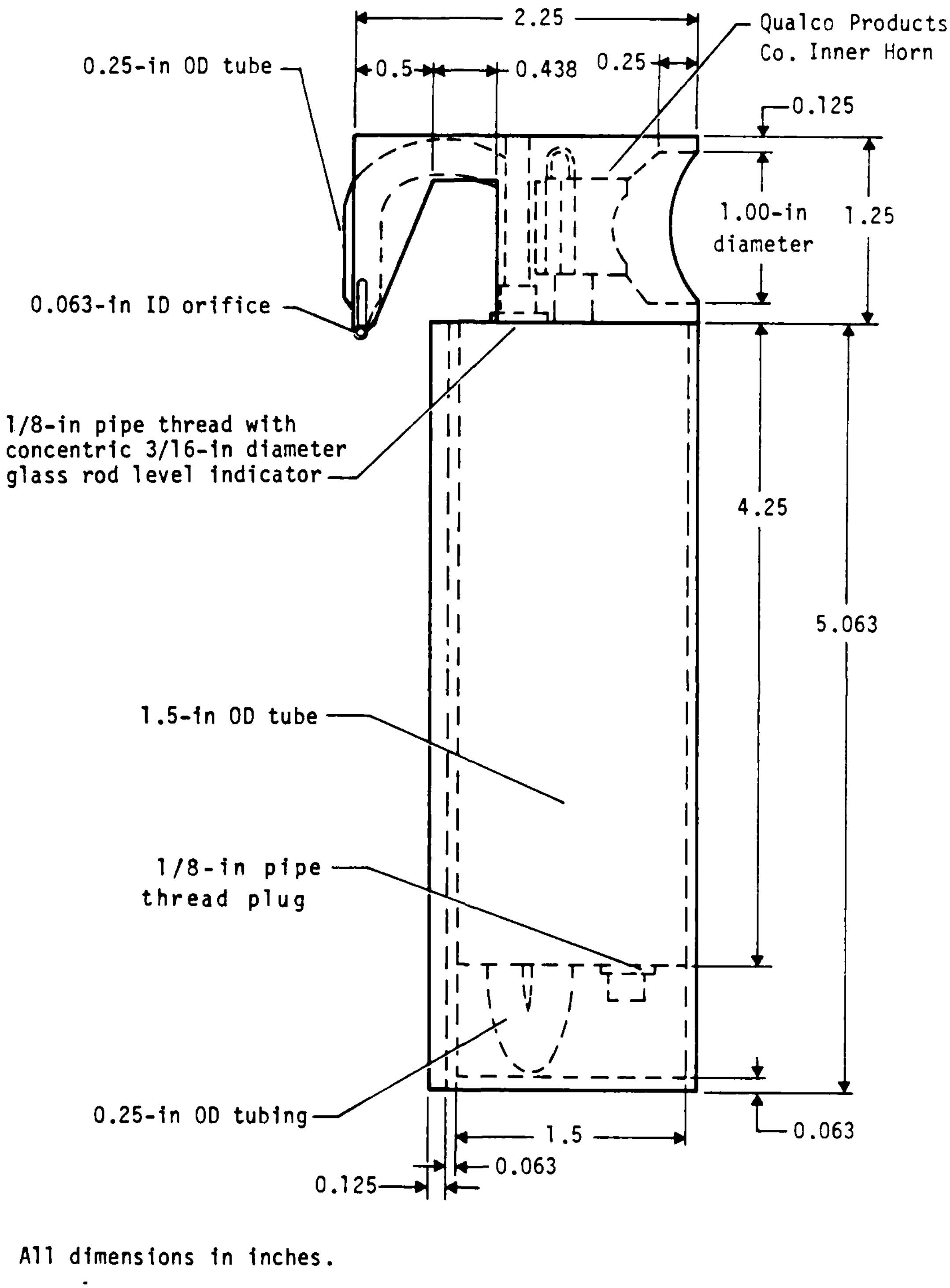
A detailed schematic drawing and functional description of the acoustic receiver circuitry developed for testing during this project is presented in Appendix B. The circuitry described here was developed for test purposes to verify the acoustic alarm detection concept and is not recommended as a final acoustic receiver design. The acoustic receiver described in this section did verify the acoustic alarm detection concept (see Section III, Test Program) and provides a good basis from which to develop a final receiver design. Testing with this design indicated the need for further improvements and refinements in the microphone, passband definition, and discrimination criteria values. Recommended circuit modifications are presented in more detail in Appendix B.

SPECIFICATIONS

Figure 33 shows detailed drawings of the SAFE CAN extinguisher/ alarm prototypes developed and tested during the effort documented in this report. Table 3 lists component specifications. Specifications for the acoustic receiver unit are provided in Appendix B.

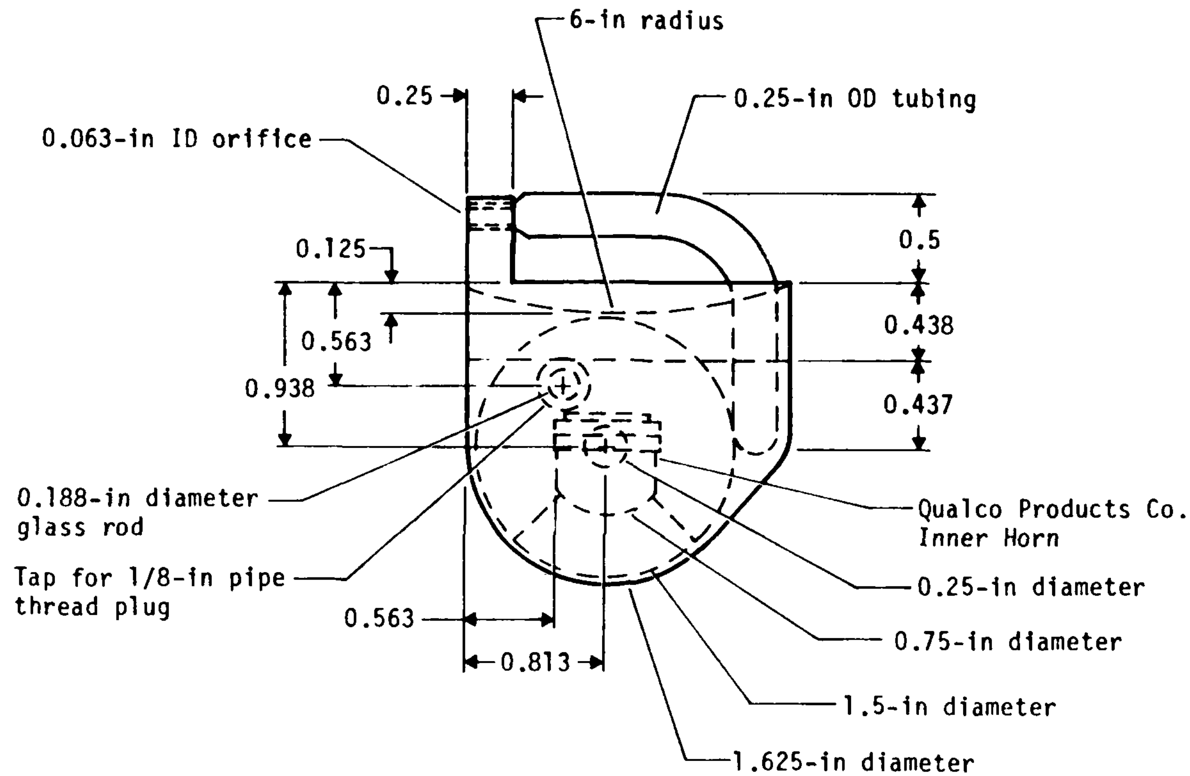
COST ANALYSIS

A major design objective of the SAFE CAN system was low cost. It was desired that the cost of the extinguisher/alarm unit be less than $5 in quantities of 10,000. To achieve this goal it was necessary that the number of parts and assembly steps required for the manufacture of the unit, as well as material costs, be minimized.



a. Side view

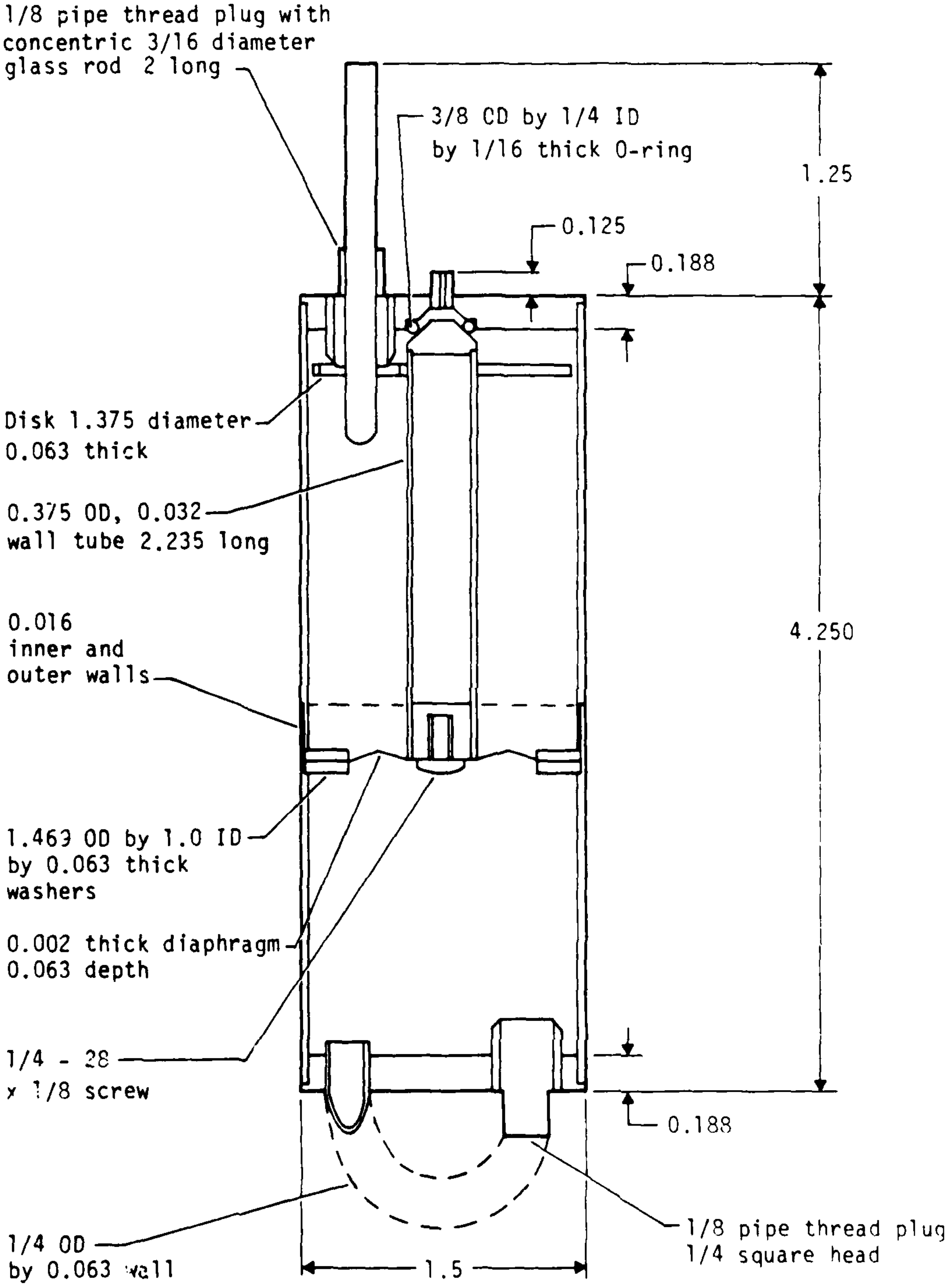
Figure 33. Extinguisher/Alarm Prototype Dimensions.



All dimensions in inches.

b. Top view

Figure 33. Continued.



All dimensions in inches

c. Section

Figure 33. Concluded.

TABLE 3. EXTINGUISHER/ALARM COMPONENT SPECIFICATIONS

Component	Specification
Extinguishing agent	
Type	Halon 1211
Quantity	0.0938 lbm (small can) 0.3127 lbm (large can)
Alarm Fluid	
Type	Halon 1211
Quantity	0.188 lbm
Container	
Material	Brass
Upper volume	3.65 in^3
Lower volume	2.43 in^3 (small can) 8.11 in^3 (large can)
Pressure rating	200 lb/in^2
Diaphragm	
Material	Brass
Travel	1/8 in
Resistance	Less than 5 lbf
Cycle life	1
Pressure rating	200 lb/in^2
Valve	
Type	Cone into O-ring
Cone material	Brass
O-ring material	Viton
Cone bevel	45 degrees
O-ring dimensions	3/8 in OD by 1/16 in thick
Exterior Tube	
Length	Greater than 8 in
Diameter	1/4 in OD, 1/32 in wall
Orifice	1/16 in ID 1/4 in long
Orifice discharge rate (Halon 1211 70°F)	0.032 lbm/s
Fusible alloy temperature	136°F
Alarm	
Type	Vibrating-diaphragm vapor horn
Frequency (fundamental)	2650 Hz
Intensity	90 dB at 1 ft
Duration	60 seconds
Cover	
Material	Nylon
Mounting	Contact adhesive

One major cost that is essentially independent of the extinguisher unit design is the cost of the Halon 1211. To produce a 25-percent design concentration in the 20-gallon waste receptacle, 4.723 cubic inches or 0.312 pounds of Halon 1211 are required. At a cost of $2.04 per pound, the cost of the Halon 1211 is $0.64. An additional 0.188 pound of Halon 1211, costing $0.38, is required to drive the acoustic alarm. Thus the total Halon cost required by the design is $1.02, leaving roughly $3.98 to fabricate and fill the extinguisher/alarm unit.

The extinguisher/alarm unit design provided in this report is basically very simple. However, to facilitate prototype construction and refinement, the prototypes were constructed from a large number of pieces requiring a large number of fabrication steps. Also a relatively expensive material, brass, was used in the prototype construction. A breakdown of the prototype extinguisher/alarm unit material costs is provided in Table 4.

TABLE 4. COST ANALYSIS: SAFE CAN DESIGN (PROTOTYPE DEVELOPMENT)

Material:	Brass	$3.40	300 g (0.66 lbm) @ $5.15/lbm
	Halon	1.02	227 g (0.50 lbm) @ $2.04/lbm
	Nylon	3.00	
	O-ring	0.10	
	Solder	0.10	
	Alarm	0.20	
	Total	$ 7.82	

Although the total indicated cost of $7.82 per unit exceeds the design goal of $5, mass production could significantly reduce this cost. For example, the cost of an extruded aluminum aerosol container of comparable volume to the brass prototype with a valve is $0.38 in quantities of 25,000. The nylon cover for the prototype was machined from a block with more than half the original mass wasted. Injection molding of the cover could eliminate this waste and reduce the mass of the prototype cover by 25 to 30 percent. The cost of the other components would also be less in quantity.

VARIATIONS

Two variations of the SAFE CAN extinguisher/alarm unit design are suggested which may facilitate production and reduce unit cost. The first locates the diaphragm and alarm valve mechanism outside of the extinguishing fluid and alarm fluid containers. This would allow freedom in the manufacture of these components while utilizing standard aerosol containers and filling techniques for the two fluids. The second variation would utitlize plastic for most of the SAFE CAN construction. All components, with the exception of the Viton® O-ring valve seat, the metal heat detector tube, and the fusible alloy seal could be molded from plastics. Nylon and acetal plastics, such as Celcon® and Delrin®, are suggested; however, few compatibility data are currently available for these plastics when used with Halon 1211.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A fire protection system which automatically detects and extinguishes fires in administrative waste receptacles and provides local alarm and notification to the fire department has been designed, developed, and successfully tested. The system consists of a small, self-contained capsulized extinguisher/alarm unit, which mounts on the waste receptacle, and a remote acoustic detector which recognizes the local alarm and generates a signal to notify the fire department. Full details of the final design with proven performance is presented in Section IV.

The extinguisher/alarm unit is unobtrusive and will not interfere with the normal use of the waste receptacle. It provides unsupervised extinguishment of Class A, B, and C fires within the receptacle using Halon 1211 as an extinguishing agent. The acoustic alarm is also powered by Halon 1211, thus requiring no batteries which may discharge with time. The extinguisher/alarm unit design offers the potential of unit costs less than $5 in quantities of 10,000 or more. The toxic products generated in the extinguishment process should not reach hazardous concentration in normal work spaces.

The extinguisher/alarm unit design provided in this report utilizes materials and fabrication techniques that are for reusable testing during development. The use of standard aerosol containers and fittings will reduce unit costs significantly. Manufacturing designs should be incorporated for mass production. Manufacture of the extinguisher/alarm unit from plastics also offers potential cost savings. Promising plastics such as nylon, Celcon®, and Delrin® should be investigated and tested for long-term (5 to 10 years) compatibility with Halon 1211 in this application.

The environmental noise tests and acoustic coupling tests performed during this effort were intended to verify the acoustic coupling concept. The concept was successfully verified. The potential exists for extending the coupling range and improving the receiver's false alarm rejection capability; suggested refinements to the receiver circuitry are provided in Appendix B.

Extensive measurements are needed to establish guidelines for installation of the SAFE CAN acoustic coupling system. Optimization testing should be performed to determine allowable range, optimum signal threshold settings, and optimum time-constant settings in a variety of acoustic environments if the system is to be utilized most effectively and economically.

Although SAFE CAN was designed and tested for use in administrative waste receptacles, there are numerous other applications where the extinguisher/alarm relay concept* could be utilized to reduce fire protection costs and limit fire damage. Computer cabinets, electronic equipment, utility rooms, storage rooms, cooking areas, and other small or local fire source locations could all benefit from a SAFE CAN-type system. These other potential applications of SAFE CAN should be pursued, either in total, or in part, with variations.

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*A patent is being sought.

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